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RADC-TR- 68-204
Final Report

COMPACT RADAR REFLECTIVITY RANGES
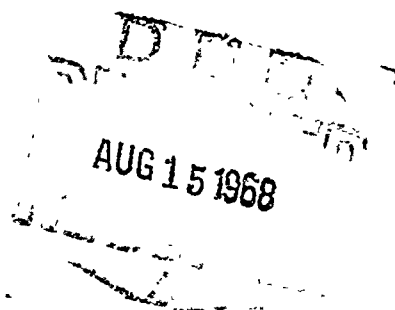
H. A. Ecker
R. A. Moore

Engineering Experiment Station
Georgia Institute of Technology

TECHNICAL REPORT NO. RADC-TR- 68-204
July 1968

AUG 1 5 1968

Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, New York

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COMPACT RADAR REFLECTIVITY RANGES

H. A. Ecker
R. A. Moore

Engineering Experiment Station
Georgia Institute of Technology

FOREWORD

This Final Report was prepared by Dr. H.A. Ecker and Mr. R.A. Moore of Georgia Institute of Technology, Engineering Experiment Station, Atlanta, Georgia, under Contract AF 30(602)-4269, with the Rome Air Development Center, Air Force Systems Command, Griffiss Air Force Base, New York. Research described in this report was performed during the period July 1967 to April 1968. The contract was initiated under Project 4506, Task 450604, with Mr. Martin Jaeger (EMATA), Rome Air Development Center as the Project Engineer.

The results of this program were made possible because of the combined efforts of several persons at Georgia Tech and Rome Air Development Center. Special thanks go to Dr. R.C. Johnson of Georgia Tech for his suggestions and interest in the program. Special thanks also go to Mr. Jaeger of RADC for his interest in the development of the Compact Ranges.

This Technical Report has been reviewed and is approved.

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ABSTRACT

The purpose of the work described in this report was to investigate the possibility of applying the concepts employed in the compact antenna ranges to the operation of compact reflectivity ranges. This work was conducted at X-band frequencies (8.2 to 12.0 GHz). A continuous wave (CW) breadboard radar was fabricated using common laboratory components and equipment. This CW breadboard radar comprises the transmitter and receiver equipments used with the compact range reflectors.

Selected test targets, whose theoretical backscatter patterns were calculable, were used in the investigation. The backscatter patterns of these test targets as a function of azimuth angle were measured using the point-source and line-source CW reflectivity ranges. Comparisons were made of the measured backscatter patterns and the calculated theoretical backscatter patterns. The test targets varied in physical area from a 4 square-inch flat plate to a 100 square-inch flat plate. A 2.5 inch diameter conducting sphere was used as the calibration target.

A study of target support structures for use on reflectivity ranges led to the fabrication of a cellular plastic (Styrofoam FR[1]) right conical column with a serrated surface. The serrated surface was designed to produce diffuse rather than specular scattering from the support structure.

The sensitivity level of the developed compact CW reflectivity ranges is limited by vibration to -50 dBsm for the line-source range and -40 dBsm for the point-source range. This sensitivity or null level limits the measurement of radar cross section to values greater than -40 dBsm and -30 dBsm, on the compact line-source and the compact point-source reflectivity ranges, respectively. The collimated beam illumination characteristics of the compact ranges limit the measurement of radar cross section to targets approximately 36 inches in diameter or smaller. Measured backscatter patterns obtained on both compact reflectivity ranges compare very favorably to those calculated.

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[1]A registered trade name of the Dow Chemical Company

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EVALUATION

1. This continuation effort consisted of a study and investigation to
improve the measurement accuracies of existing X-band breadboard model
compact antenna ranges and to extend the operating frequencies to the
C and S-band regions. The effort also included an investigation of the
application of compact range techniques to radar reflectivity measurements.

2. The compact range technique utilizes incident plane waves produced
by a reflector and special feed system in the near field of the test
antenna to obtain far-zone measurement results. The two configurations
investigated consist of a point source range and a line source range.
A parabolic reflector with a horn feed is used in the point source range
and a parabolic cylinder reflector with a hog horn feed is used in the
line source range. Under prior contract AF30(602)3594, it was demonstrated
that X-band antenna pattern and gain measurements could be conducted on
each of these ranges in a 4 ft. square indoor test area, and the results
compared favorably with those obtained from measurements made on a
conventional 700 ft. test range. This work was discussed in RADC-TR-66-15,
Final Report, entitled, "Compact Antenna Range Techniques", dated Apr 66.

3. In the continuation effort, both ranges were modified by providing
range reflectors having a more accurate surface contour and by shielding
the point source reflector edge and its feed with absorbing material. In
addition, C and S-band feeds were designed and fabricated for the point
source range. The measured stray radiation levels (relative to collimated
energy) on the modified ranges at X-band are about -44 to -59 db for the
point source range and -40 to -58 db for the line source range. Compared
to previously constructed compact ranges, stray radiation on the modified
point source range was reduced approximately 10 db, and stray radiation on
the line source range was reduced about 2 db. The above improvements
increased the accuracy of antenna pattern measurements. The side lobe
measurement accuracy at the -30 db level is $\pm$ 1 db. C and S-band antenna
patterns measured on the point source range compared well with those
measured on the conventional 700 ft. range. Work on the modified compact
antenna ranges is reported in RADC-TR-67-12, dated Mar 67 and RADC-TR-67-
473, dated Oct 67.

4. This report describes the results of investigations which applied
existing compact antenna range techniques to radar reflectivity ranges at
X-band. Both the point source and the line source compact antenna ranges
were converted to reflectivity ranges. This was accomplished by using the
same range illuminators with breadboard CW radar equipment, existing
receiving and recording equipment and a styrofoam target support structure

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mounted on the existing azimuth-over-elevation positioner. Range
investigations at frequencies from 8.2 to 12 GHz included stray radiation
measurements; the effect of target position relative to the range illumin-
ator; range sensitivity; and comparisons between measured and theoretical
radar cross-section of standard targets such as spheres, flat plates and
corner reflectors. Results of the above effort demonstrated that the
X-band CW compact reflectivity ranges can measure with an accuracy of
+ 1 db the backscatter patterns of radar targets as a function of aspect
angle. The sensitivity level of the point source and line source
reflectivity ranges is -40 db sm and -50 db sm, respectively. The largest
physical dimension of targets that can be measured is approximately 3 ft.
Larger targets would have to be scaled in size.

5. Requirements of specifications have been met and the program has been
brought to a successful conclusion. The design information provided as a
result of study efforts accomplished on both the compact antenna ranges and
compact radar reflectivity ranges have been useful to Government R&D
agencies in conducting laboratory experiments. This is evidenced by the
number of inquiries made for past and future reports. Advantages of the
compact range techniques include reduced range requirements, reduction in
operating personnel, lower RF transmitter power and freedom from adverse
weather conditions.

MARTIN JAEGER
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RADC, GAFB, NY

SECTION I

INTRODUCTION

One of the primary requirements for a valid measurement of an antenna far-field pattern or the radar reflectivity of a target is that the test antenna or radar target be illuminated by a uniform plane wave. In outdoor ranges this condition is approximated by separating the transmitter and receiver sufficiently such that a spherical wave approximates a uniform plane wave in the neighborhood of the test antenna or target. An alternate method that requires much less space is to use a collimating device such as a lens or reflector to produce a uniform plane wave.

Georgia Tech has demonstrated that a reflector and special feed system can be used to produce incident plane waves for the measurement of far-zone antenna patterns in the near field of the test antenna.[1,2] These compact antenna ranges have produced results which compare favorably with better than average outdoor antenna ranges. Two compact range configurations were studied: a point-source range and a line-source range. A paraboloidal reflector with a horn feed is used in the point-source range whereas a parabolic cylinder reflector with a hog-horn feed is used in the line-source range.

The previous success at Georgia Tech with compact antenna ranges led to speculation on the applicability of these techniques to radar reflectivity ranges. The research program described in this report

is an investigation of applying compact range techniques to radar re-
flectivity ranges at X-band   A CW X-band radar was built, and both
the point-source and line-source compact antenna ranges were converted
to reflectivity ranges.

In addition to stray radiation measurements described in previous
Georgia Tech reports,[1,2] the primary evaluation of the reflectivity
ranges consisted of comparisons between measured and theoretical radar
cross-section patterns of standard targets, such as spheres, flat plates,
dihedral corners, and trihedral corners. The effect of the position of
the target relative to the reflector, the sensitivity of the ranges,
and the dynamic range over which valid measurements could be made were
all investigated. Descriptions of the operation of the two compact
reflectivity ranges, measurement procedures, and the results of reflec-
tivity measurements on test targets are included in this report. Also,
brief discussions on frequency scaling and the use of short-pulse radar
with the compact ranges are presented.

SECTION II

DESCRIPTION OF COMPACT REFLECTIVITY RANGES

A. Radar Cross Section

When a radar target is illuminated by a linearly polarized wave, the radar cross section or echo area, σ, is defined as

$$\sigma = \lim_{R \to \infty} 4\pi R^2 \frac{|E_x^s|^2}{|E_x^i|^2} \qquad (1)$$

where R is the distance between the radar target and the measurement antenna, $\overline{E_x^i}$ is the incident electric field at the target, and E_x^s is the x component of the scattered field at the antenna. It follows from this definition that the incident wave must behave as a uniform plane wave in the neighborhood of the target; that is, the amplitude and phase of the incident field must be essentially uniform over the physical area of the target. The basic feature of the Georgia Tech compact ranges is the generation of the required uniform plane wave with large collimating reflectors thus eliminating the need for long ranges.

B. Reflectors

The reflector systems for the point-source and the line-source compact reflectivity ranges are located in a basement room of the Electronics Research Building at Georgia Tech. No special provisions were incorporated

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into the construction of the room to reduce reflections or interference.
A plan view of the locations of the various components of the reflectivity
ranges is shown in Figure 1. The reflectors for the two compact ranges
are positioned to permit the same X-band CW radar system and target sup-
port structure and pedestal to be used with both reflector systems.

The characteristics of the two reflector systems have been described
previously.[1,2] The point-source range employs a ten-foot paraboloidal
dish with an F/D ratio of 0.25. The feed is oriented to produce the peak
of the feedhorn radiation pattern at the center of the top half of the
reflector as shown in Figure 2. This orientation was chosen to reduce
reflection and defraction from the feed and its supports and to give
approximately uniform illumination in the central portion of the upper
half of the reflector. The size of target that can be measured is re-
duced by this feed orientation; however, a more nearly uniform plane
wave is generated in the test area than would be possible with the feed
aimed toward the center of the dish.

A specially constructed hog-horn forms a tapered illumination line-
source to feed a parabolic cylinder in the line-source range. The
collimating reflector is a section of a parabolic cylinder approximately
9 feet wide and 6 feet high. The parabolic barrier in the hog-horn feed
is estimated to conform to a true parabolic contour within ± 0.004 inch.
Measurements indicate that the surface of the parabolic cylinder conforms
to a true parabolic cylinder within about ± 0.010 inch. Figure 3 shows

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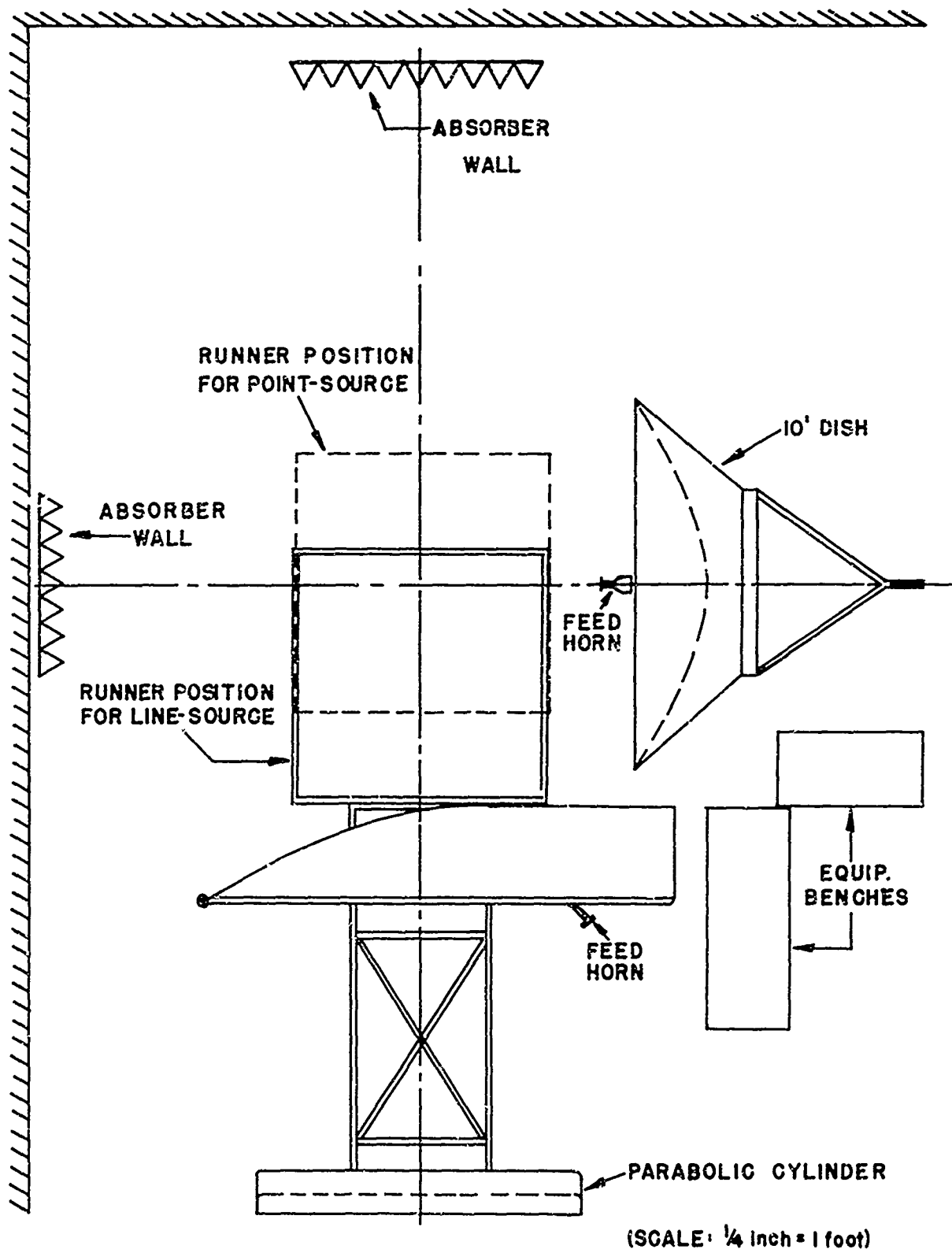
Figure 1. Plan view of Compact Reflectivity Ranges
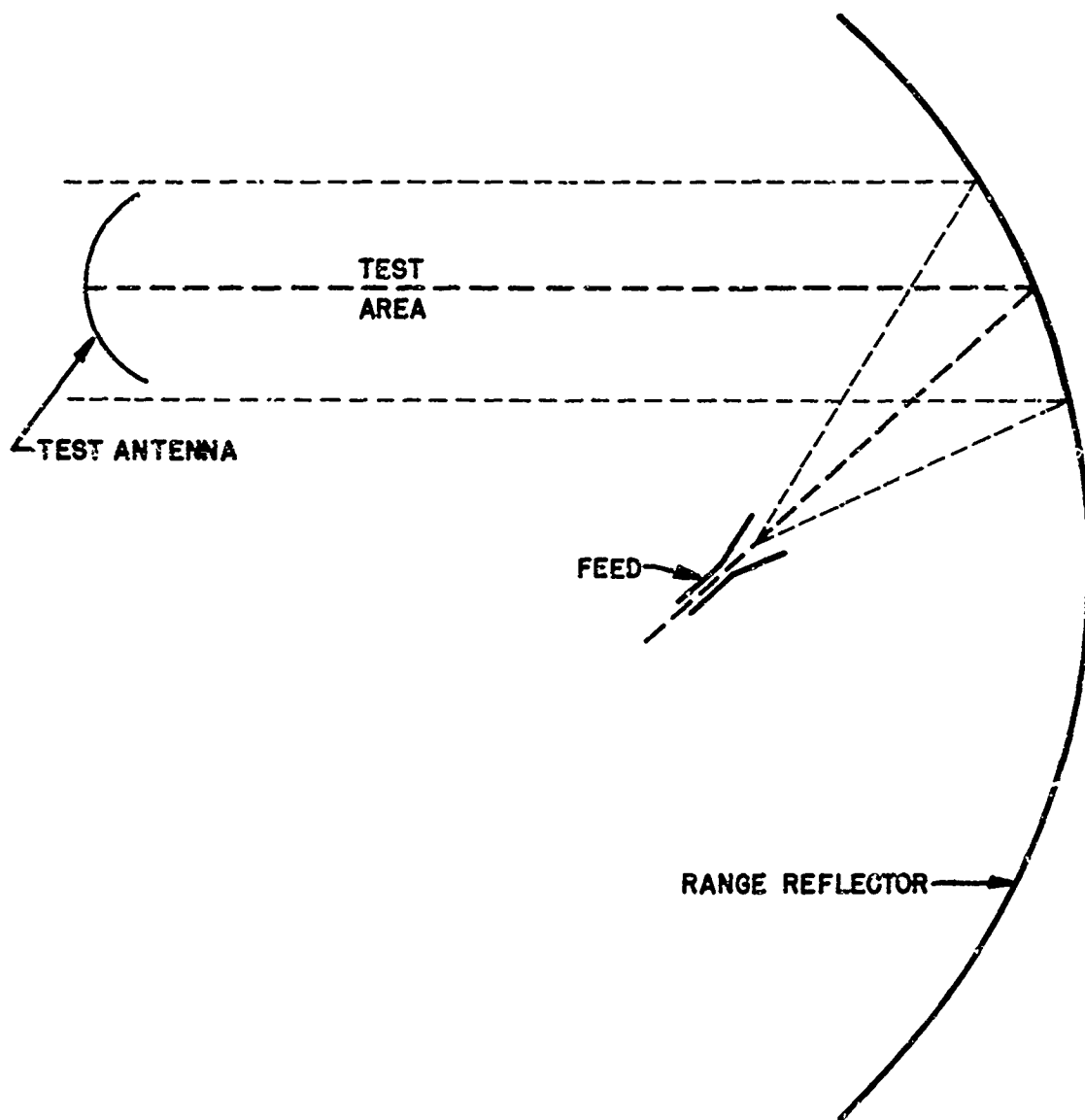
Figure 2. Schematic drawing of the point-source compact antenna
range showing the available test region

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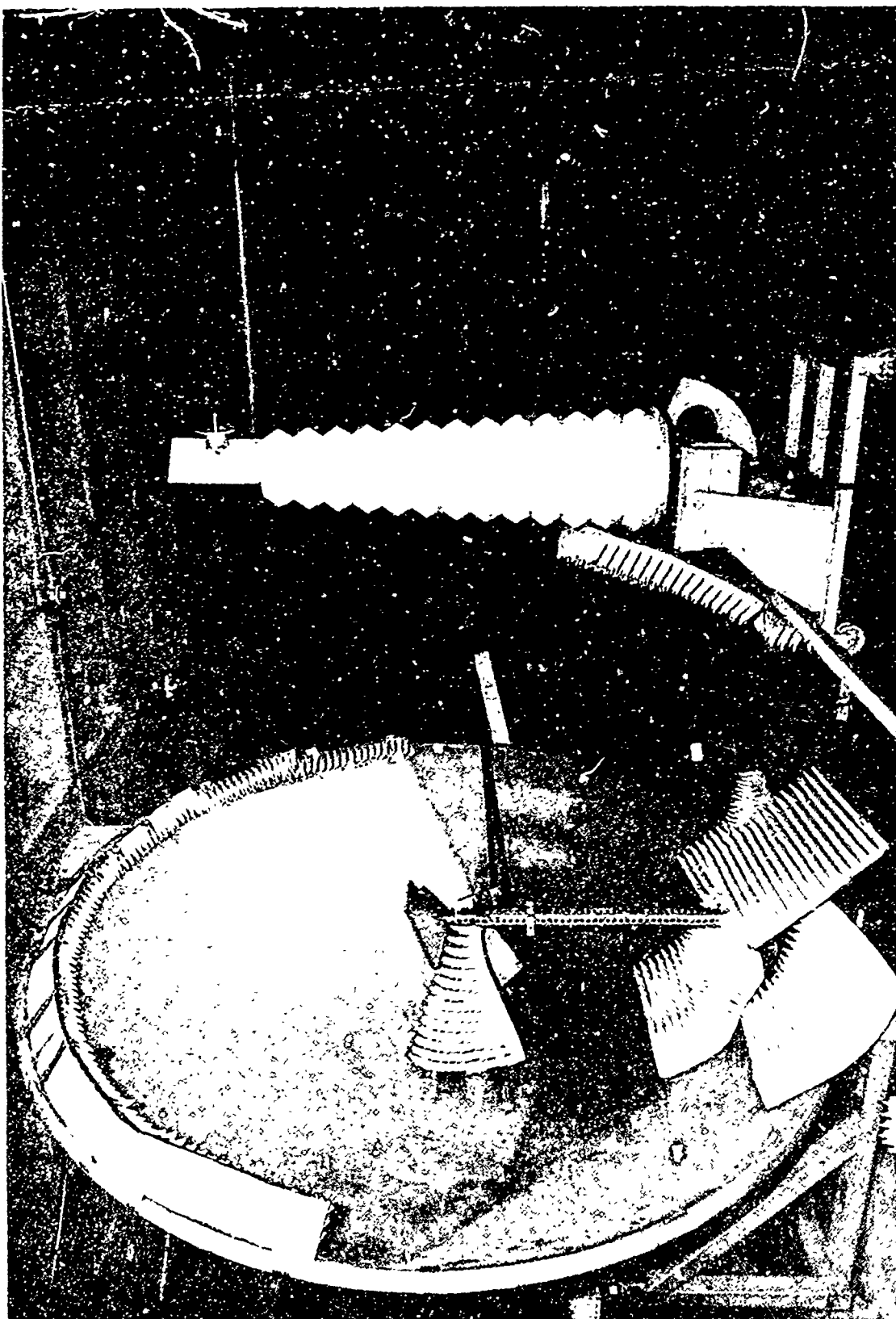
Figure 1. Photograph of the Compact Reflectivity Ranges and the Styrofoam target support structure

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a photograph of the two reflector systems with a dihedral corner mounted on the Styrofoam support structure.

C. Stray Radiation

The locations of the point-source and line-source reflectors in the compact reflectivity ranges were different from those used in previous studies of compact antenna ranges. Measurements of stray radiation level were made in these new locations to insure that additional stray radiation had not been introduced by the changes in reflector positions. The maximum stray radiation level as a function of azimuth angle off the reflector axis was measured by the same procedure described previously in Georgia Tech reports on compact antenna ranges.[1,2] For these measurements the ranges were set up as compact antenna ranges with a 30-inch paraboloidal dish used as the test antenna. The measurement procedure can be summarized as follows·

1. The test antenna was rotated in the azimuth direction to receive power on a particular side lobe.

2. The test antenna was then moved in the direction of propagation of the uniform plane wave from the reflector; i.e., parallel to the axis of the reflector.

3. The change in the apparent level of the side lobe due to the change of relative phase between the collimated radiation and the stray radiation with position of the test antenna was recorded.

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4. The peak-to-peak variation with position of the test antenna
    of a particular side lobe was used to calculate the magni-
    tude of the maximum stray radiation.

5. The same procedure was repeated for other side lobes, and
    the stray radiation level was generated as a function of
    azimuth angle with respect to the reflector axis.

Figure 4 shows a photograph of the compact ranges with the 30-inch
test antenna mounted to make stray radiation measurements. The maximum
stray radiation level was measured for both the point-source and the line-
source compact ranges. Figures 5 and 6 show the results of these measure-
ments for three frequencies in X-band. The stray radiation levels are
comparable to those measured with the reflectors in their previous
locations.

D. CW X-band Radar

For simplicity of construction and compatibility with pattern re-
cording equipment, a CW radar design was chosen for the compact reflectivity
ranges; a block diagram of the X-band CW radar is given in Figure 7. The
system was built with standard laboratory equipment, and the receiver and
pattern recorder are Scientific-Atlanta equipment normally used in antenna
ranges.

In a CW reflectivity range of any type, a very stable frequency
source is a prime requirement. A tunable synchronizer used to phase-lock

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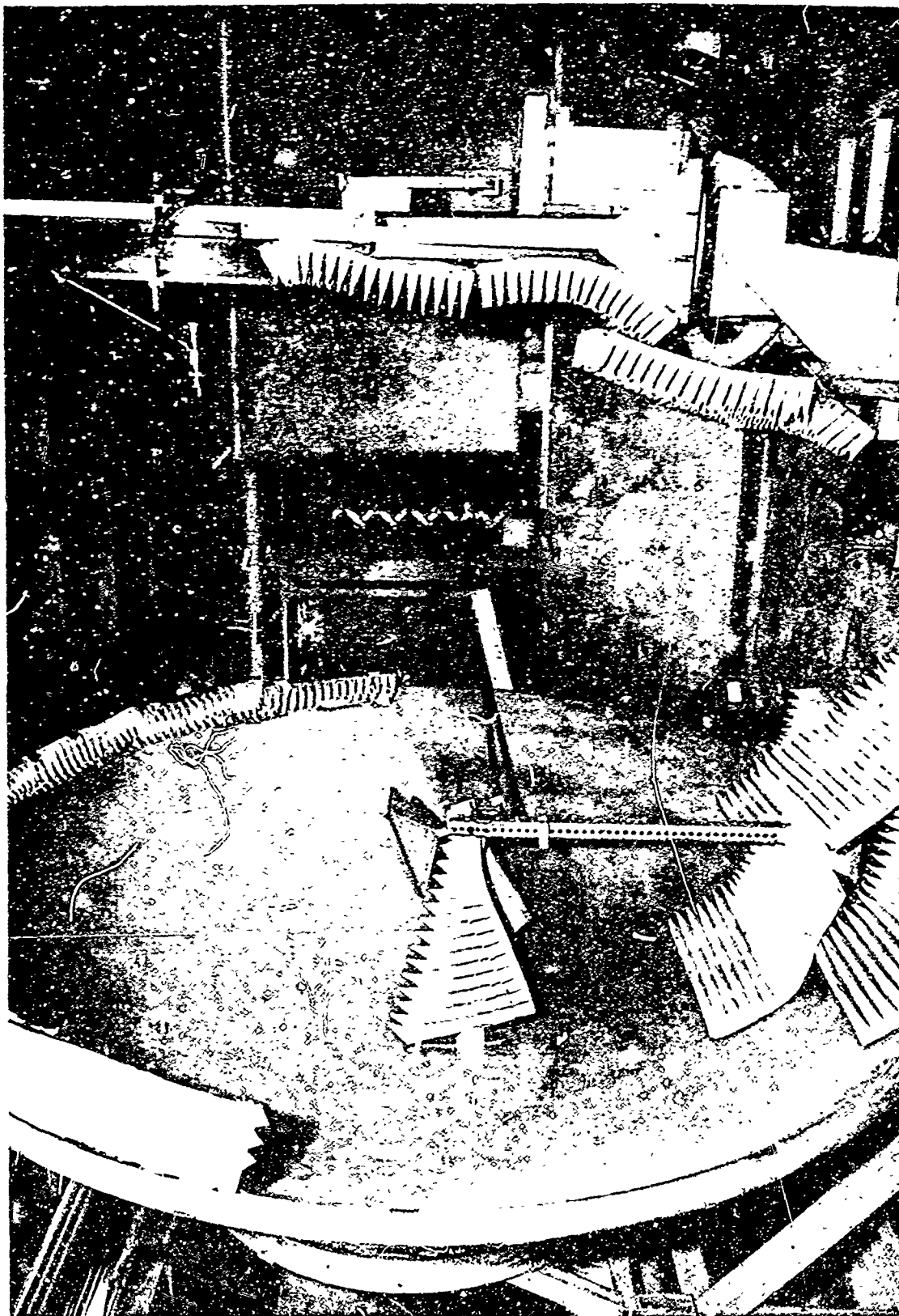
Figure 4. Photograph of the compact ranges with the 30-inch test antenna in position
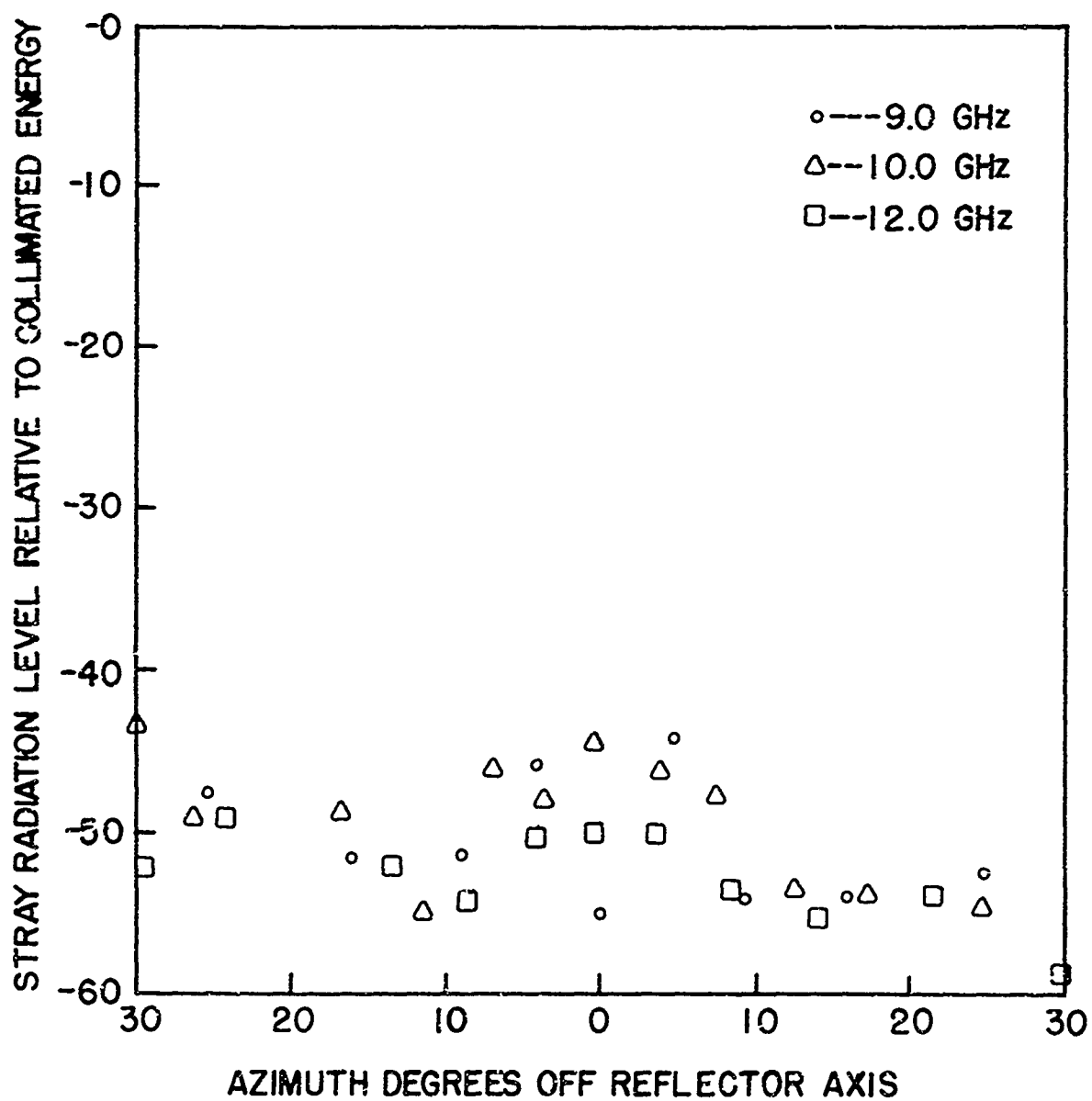
Figure 5.   Maximum stray radiation levels as a function of azimuth
            angle of the 30 inch diameter test antenna as measured
            on the point-source compact antenna range

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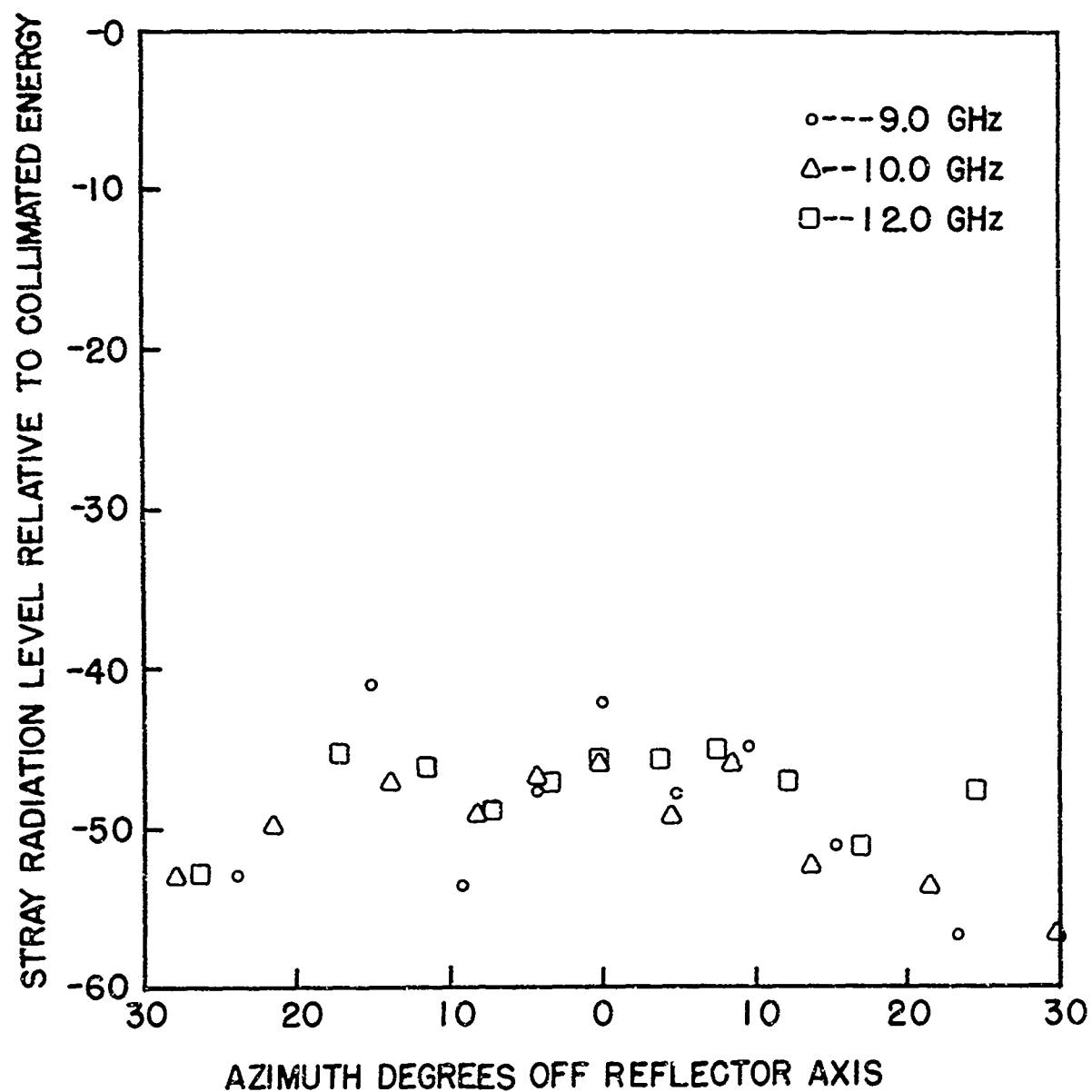
Figure 6. Maximum stray radiation levels as a function of azimuth angle of the 30 inch diameter test antenna as measured on the line-source compact antenna range

Figure 7. Block diagram of the X-band CW radar

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an X13 reflex klystron is the stabilized frequency source for the com-
pact reflectivity ranges. The frequency of the klystron is tunable from
8.2 GHz to 12.4 GHz, and short-term stability of one part in 10^8 per
second is made possible with the synchronizer. A nominal 15 mw of out-
put power is available from this source.

As shown in the block diagram in Figure 7, a small portion of the
transmitted signal is coupled into a channel for frequency measurement
and for input into the klystron synchronizer. The sample of the trans-
mitted signal is compared with the frequency reference in the synchronizer.
An error signal is generated which continually controls the repeller
voltage on the reflex klystron to maintain frequency stability.

A magic-tee hybrid junction is used as a duplexer for the CW radar.
After passing through an isolator, the input signal from the transmitter
is divided equally to provide a transmitting signal to the antenna sys-
tem and a signal as input to a slide-screw tuner. A return signal from
the antenna or from the arm containing the slide-screw tuner is equally
divided to provide output signals in the transmitter arm and the re-
ceiver arm of the magic-tee. The isolators in these two arms of the tee
permit the signal to pass to the receiver but do not allow the signal
to pass to the transmitter.

Several wide-band, Scientific-Atlanta receivers, including the new
1750 series phase amplitude receiver, are available for use in the X-band
CW radar. With the Scientific-Atlanta 1750 receiver in the system, both

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phase and amplitudes of the scattered wave can be measured simultaneously.
A standard Scientific-Atlanta pattern recorder is used to record the radar
reflectivity patterns.

After the frequency of operation has been selected, the synchronizer
is adjusted to achieve a phase-lock condition. Then with only the sup-
port structure in the range, the slide-screw tuner is adjusted to produce
a minimum signal at the receiver. The slide-screw tuner adjustment
produces a reflected signal in that arm that cancels the reflected signal
from background and support structure. Thus, when a target is introduced
into the range, the signal to the receiver represents only the reflected
energy from the target.

E. Range Performance Characteristics

In a CW reflectivity range the lowest value of radar cross section
that can be measured is determined by the depth of the null for background
cancellation. Implied in this statement is that the receiver in the re-
flectivity range equipment has sufficient sensitivity not to be a
limiting factor. Two factors which control the depth of the null are
the frequency stability and any vibrational movement of the background
or collimating reflector systems. When the synchronizer was used to main-
tain high frequency stability for the transmitter, vibrations appeared to
be the limiting factor on the null level. The null levels for the point-
source and line-source ranges were measured to be equivalent to radar cross
section values of -40 and -50 dB below one square meter, respectively.

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No special provisions were made to shock-mount the collimating re-
flectors or to reduce any vibrations in the background structure. Although
the entire system of the reflectivity ranges is located on a concrete slab
in a basement room, when the slide-screw tuner was adjusted to obtain the
best null, vibrations resulting from a person walking across the concrete
floor would cause variations in the null level. The difference in the
vibration level for the two ranges is caused by the difference in weight
of the two reflector systems and the different mounting techniques. The
point-source reflector is lighter than the line-source reflector and also
is mounted with a cantilever structure; thus the point-source range has a
higher vibration level than does the line-source range.

Previous measurements of the nature of the wave from the collimating
reflectors from the point-source and line-source ranges indicated that a
uniform plane wave was generated in a region approximately 30 inches
square. This area is much smaller than the reflector apertures because
tapered illumination was used to reduce edge defraction, a major contributer
to the stray radiation level. It would be possible in many applications
to use targets that were somewhat larger than the 30" x 30" area men-
tioned above. It has been found that reasonable accuracy in the measure-
ment of radar reflectivity patterns is possible if the maximum variation
in phase does not exceed $\pi/8$ radians and the maximum amplitude variation
does not exceed 1 dB at the target aperture.[3] The geometrical configura-
tion of the target determines the phase and amplitude variations across

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the aperture that can be tolerated. Phase and amplitude variations of $\pi/16$ and 0.2 dB, respectively, are required for precise measurements of targets with surfaces which are essentially flat. However, if large targets with a number of nearly independent scattering centers are being measured, the phase variation may exceed π with amplitude variations of 3 dB.

Dynamic range is no problem with the CW reflectivity range as depicted in Figure 7. The large dynamic range of the Scientific-Atlanta wide-band receiver and the use of precision attenuators in the system cause the dynamic range to be limited only by the vibration level on the low end and the largest radar cross section target that can be obtained in the 30" X 30" area on the high end.

SECTION III

TARGET SUPPORT STRUCTURE FOR USE ON REFLECTIVITY RANGES

One of the major problems associated with the design of any reflectivity range to measure the backscatter patterns of radar targets as functions of aspect angles is to support the target with a structure whose backscatter does not affect the return of the test target. Several of the more common methods used to support the target to be measured are cellular plastic columns, air inflated columns, thin dielectric lines, and spin dropping the target through the incident field. For many applications, cellular plastic columns have distinct advantages over the other methods. These advantages are (1) ease of fabrication, (2) rigidity of support, (3) symmetry about an axis of rotation, and (4) low radar cross section.

Supports of the plastic column type may be constructed in various shapes. The cellular plastic columns may have a constant diameter that is determined by the frequency of operation. With proper choice of the column diameter, the backscatter of a column with low ri 'ar cross section can be further reduced. Target supports designed in this manner are referred to as "tuned columns." A more general shape for the cellular plastic column is that of a truncated right conical column. With this design shape and proper cone angle, the main specular reflection from the column can be directed away from the receiver. The backscatter from the right conical column can be reduced further by serrating or by using

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other types of symmetrical shaping of the surface of the column to make the column a diffuse rather than a specular scatterer.

Because of the many types of manufactures of cellular plastics, the Radiation Laboratory, University of Michigan, analyzed the reflectivity characteristics of a variety of cellular plastic materials when used as target support structures.[4] This study indicated that Styrofoam FR, a product of Dow Chemical Company, is one of the better cellular plastics used as target support structures on reflectivity ranges. Both theoretical and measured data were the basis for the choice of this material. Styrofoam FR is a polystyrene material composed of uniform cells approximately 0.01 inch in diameter. A distinguishing characteristic of Styrofoam FR is its light blue color.

The target support structure design requirements for the compact reflectivity ranges were the following:

1) symmetry about a vertical axis of rotation,

2) minimum radar cross section over the frequency band 8.2 to 12.8 GHz,

3) variable height to be compatible with the point-source and the line-source ranges, and

4) easy target placement and removal.

Figure 8 is a photograph of the Styrofoam target support structure. This right conical column with a base diameter of 16 inches and a cone half angle of 3.6 degrees was fabricated from Styrofoam FR material.
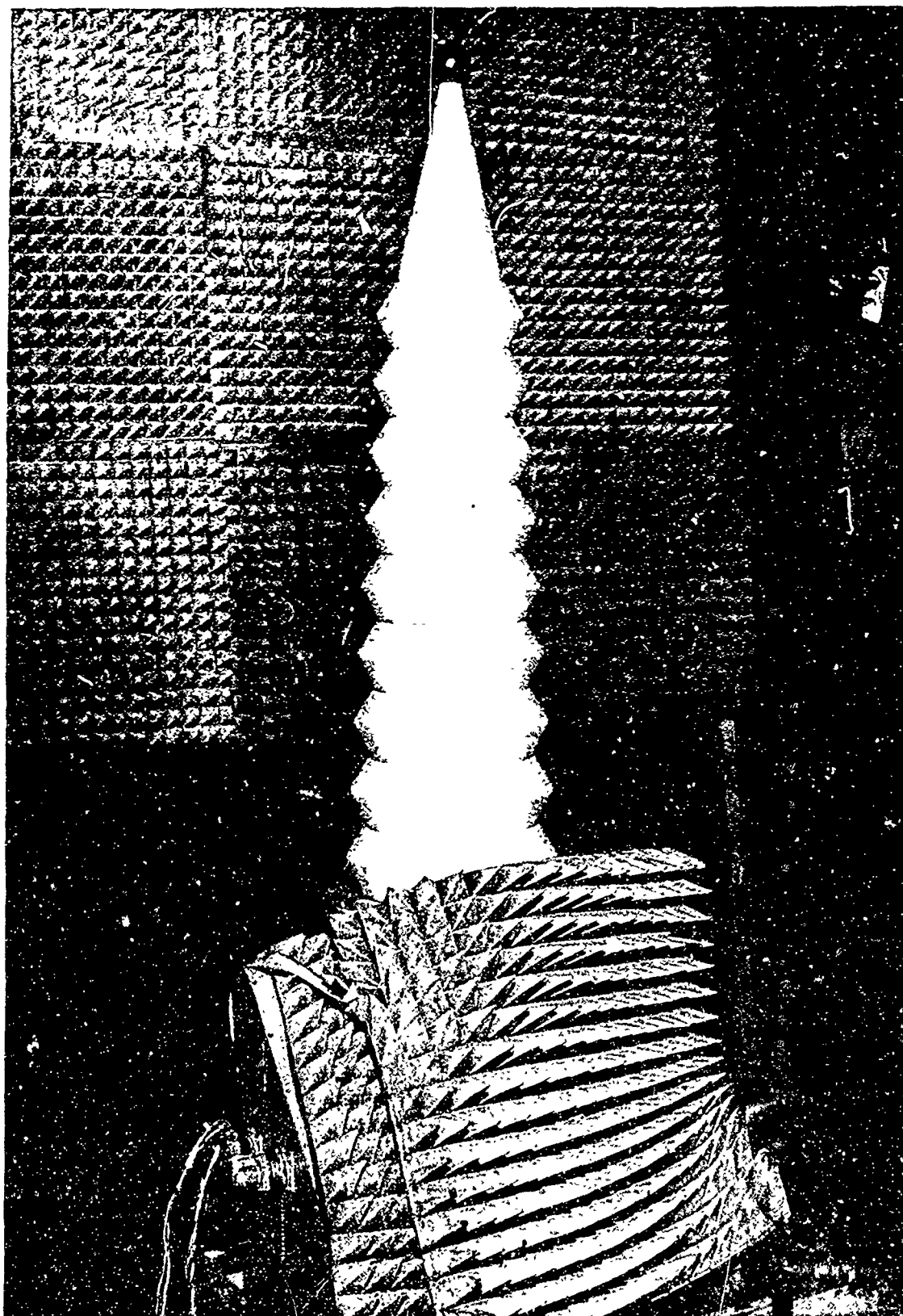
Figure 8.   Photograph of Styrofoam FR target support structure

The column was built with 4 inch thick discs of Styrofoam FR material; each disc progressively was decreased in diameter and was beveled at the edges to produce a serrated column when the discs were assembled. The conical column was truncated at a height of 60 inches thus providing a 6.5 inch platform. Another right conical section with a 6.5 inch base diameter and a cone half angle of 12.5 degrees was attached to the top of the main serrated column. This conical section also was fabricated of 4 inch discs of Styrofoam FR and designed to be truncated at 8 and 12 inch heights. This small conical section atop the main column was added to eliminate the possibility of interaction between the smaller test targets and the support structure.

In the fabrication of the discs which make up the support column, a 3/8-inch centering hole was necessary. These holes correspond to the vertical axis of the column. Three-eighths inch Styrofoam dowels were used to align the adjacent discs of the column and assured symmetry about this axis of rotation. The centering hole in the top of the support column provides a convenient and accurate means for target placement. A Styrofoam dowel adhered to the back of the flat plate target and placed in the centering hole assured rotation of the target on the vertical axis of the column and also aligned the normal of the flat surface of the target to be perpendicular to this vertical axis.

The column was mounted on the antenna positioner normally used with the compact antenna ranges. This positioner provides azimuth-over-elevation rotation; thus for the azimuth rotation of the mount, the

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column always will rotate about its axis of symmetry. The positioner is mounted on a movable table which travels on two sets of orthogonally oriented tracks. This arrangement allows movement of the test target to any position inside a 4-foot square floor area.

Adjustment of the target support structure in height was necessary so that the same structure could be utilized on both the point-source and the line-source reflectivity ranges. This requirement exists due to a 12-inch difference in height between the centers of the two collimated beams. Three removable bottom Styrofoam discs in the support column make it compatible for use on both the compact reflectivity ranges. The remainder of the discs comprising the target support column were tack glued with white glue to add rigidity to the column and to assure that the discs did not shift in position after the initial alignment.

It is relatively difficult to make measurements to determine the backscatter level of the target support column. This difficulty is due to the nature of operation of the CW reflectivity range, which requires that the background be nulled and then the target, in this case the target support column, be placed in position and the backscatter signal recorded. The backscatter signal level of the target is then compared to the backscatter signal from a standard or reference target of known radar cross section. Since in this case the target is the support column, no means are provided to support the reference target. With this in mind, measurements were taken of the backscatter returned by the

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Styrofoam FR support column, with the null level used as the reference signal. These measurements were conducted on the line-source reflectivity range, which has a sensitivity or null level of approximately -50 dBsm.[*] The greatest signal level received by placing the support column in position was 5 dB above this null; thus the radar cross section of the column is assumed to be approximately -45 dBsm.

A significant evaluation of the support structure is to determine the effect movement of the support column has on the null level. With the Styrofoam target support column in position on the pedestal and a null achieved, the column position was moved from side to side and varied in range. No noticeable variation was observed in the null level for this movement of the support column. The above check was conducted at each operating frequency; i.e., 8.2; 9.0, 9.4, 10.0, and 12.0 GHz.

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[*]dBsm is dB relative to one square meter of radar cross section

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SECTION IV

TARGETS

A. Calibration Target

The measurement of radar cross section or backscatter patterns usually is not an absolute measurement; i.e., the measurements must be referenced to some standard target of known radar cross section before numerical values may be assigned to the measured data. It is desirable that the radar cross section of the standard target be independent of aspect angle and frequency. The conducting sphere can approach these requirements and therefore is a common reference target for radar reflectivity measurements.

If care is used in construction, a conducting sphere can be made to have radar cross section essentially independent of aspect angles, but only spheres having radii much greater than the wavelength at the test frequency have a radar cross section independent of frequency. Beyond the Rayleigh region, the radar cross section of a conducting sphere oscillates as a function of wavelength about the geometrical cross section value as shown in Figure 9. A 2.500 inch diameter steel ball bearing was chosen as the standard target for calibration on the compact reflectivity ranges because of its precise construction and reasonable cost. The geometrical cross-section value for this size sphere is -25 dBsm. The theoretical radar cross section of the 2.500 inch sphere in the frequency band of interest, 8.2 to 12.0 GHz, is shown by the curve in Figure 10. A photograph of the sphere is shown in Figure 11.

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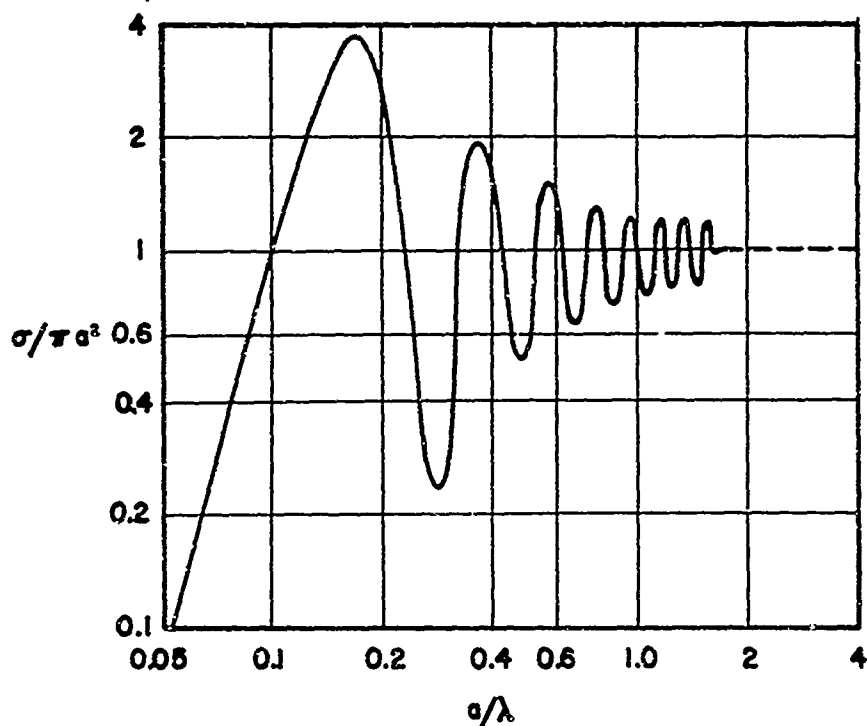
Figure 9. Ratio of theoretical cross-section to geometrical cross-section as a function of radius normalized to wavelength for a perfectly conducting sphere
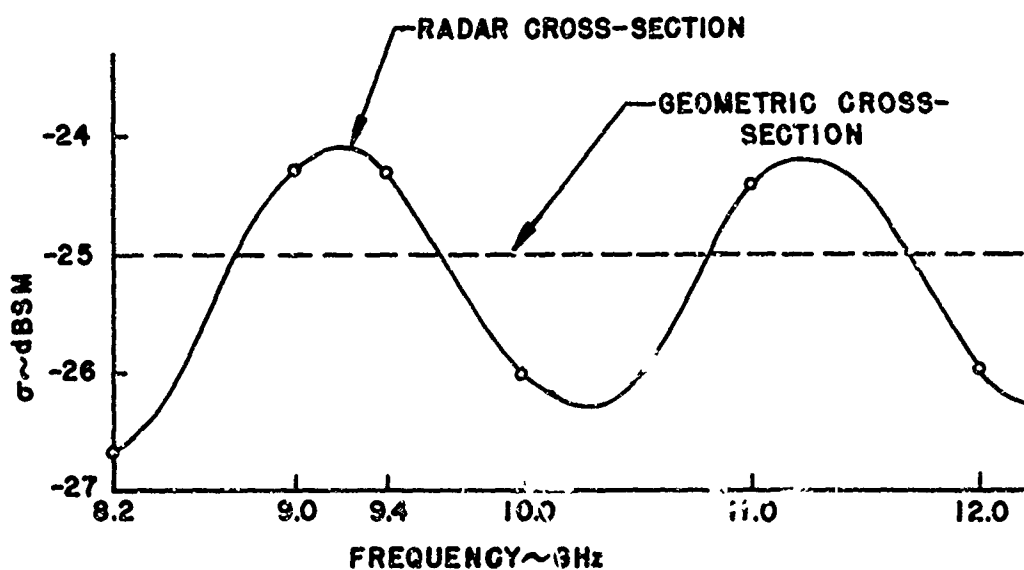
Figure 10. Radar cross-section as a function of frequency for a 2.5 inch diameter perfectly conducting sphere

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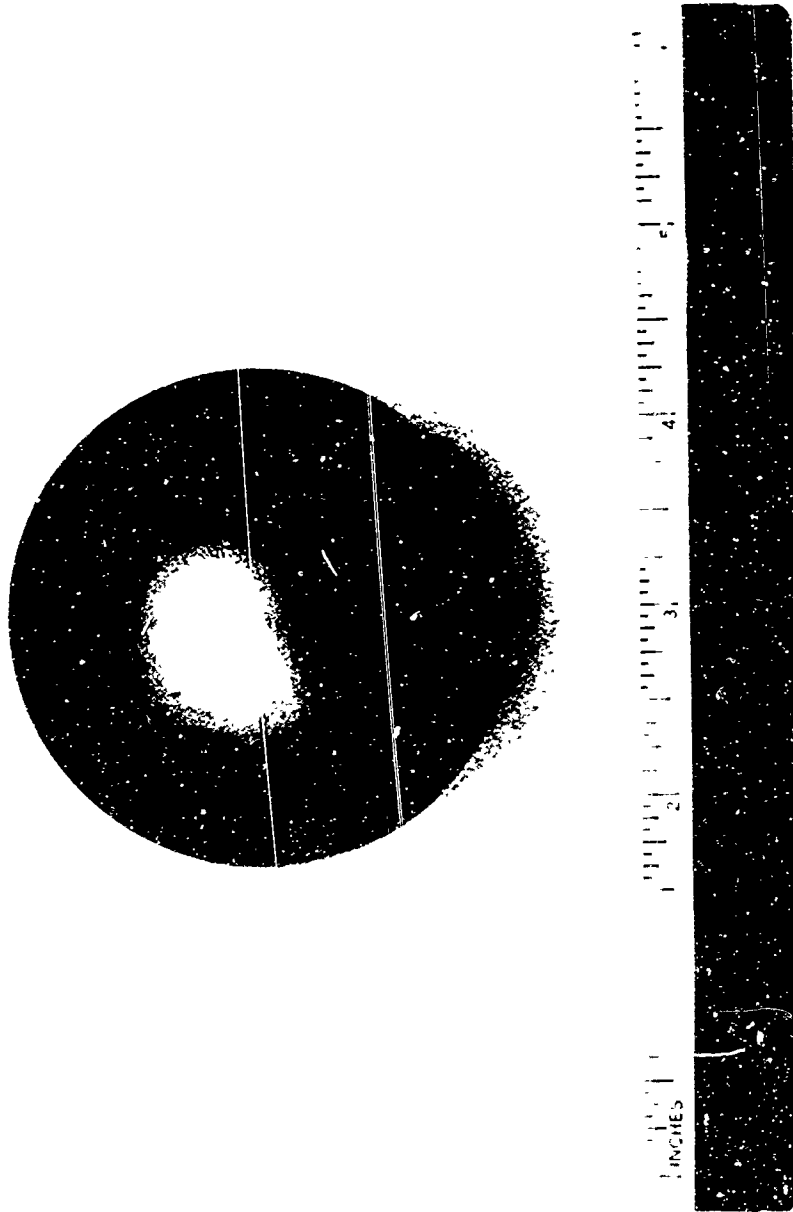
Figure 11.   Photograph of the 2.500 inch diameter calibration sphere

B. Test Targets

To evaluate the quality of the compact reflectivity ranges, the back-scatter patterns of a series of test targets were measured. One requirement of these test targets was that they have calculable backscatter patterns. It was also desirable that the backscatter patterns have specific distinguishing characteristics that would aid in comparing the theoretical backscatter patterns to the measured backscatter patterns. Flat plate type targets of both rectangular and circular aperture were selected as test targets since they satisfy the conditions described above and can be built easily.

The theoretical backscatter pattern of a flat plate is a function of many variables, each contributing some characteristic feature to the over-all backscatter pattern. The more important of these variables are the following:

1) amplitude and phase illumination across the aperture,

2) target size and shape,

3) frequency of operation,

4) edge diffraction, and

5) transmitted polarization dependence.

For the calculations of the theoretical backscatter pattern to be compared with the measured backscatter pattern, a uniform plane wave across the target aperture was considered to be the illuminating function. Thus, for a given target size, aperture shape, and frequency of operation,

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the following specific characteristics of the theoretical backscatter
pattern as a function of aspect angle are known:

1) half-power beamwidth,

2) peak radar cross section,

3) angular displacement and depth of nulls, and

4) side-lobe angular displacement and amplitude.

Geometrical diffraction theory[5] may be used to obtain the theoretical
backscatter pattern of a flat plate as a function of aspect angle and can
account for the effects of multiple edge diffraction and polarization
dependence. Although the geometrical diffraction method provides an
accurate representation of the backscatter pattern from normal incidence
to aspect angles approaching 90 degrees, the computations can be very
tedious.

Another method for calculating the theoretical backscatter pattern
as a function of aspect angle is based on the theory of physical optics.
In this method the effects of edge diffraction and polarization dependence
are neglected. Neglecting these parameters does not significantly affect
the theoretical backscatter pattern for aspect angles in the region ± 20
degrees about normal incidence.[5] Since this ± 20 degree range of aspect
angles provides a theoretical backscatter pattern of sufficient detail
for comparison with the measured pattern data, the physical optics method
was used to calculate the theoretical backscatter patterns. For a given
target size and operating frequency the mathematics of the physical optics
method is straight forward and readily adaptable to programming on a
digital computer.

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The peak radar cross section of a flat plate is the same for targets having the same physical area, but the backscatter pattern as a function of aspect angle is dependent upon the shape of the target aperture; e.g., square, rectangular, or circular apertures have different backscatter patterns. The test targets were designed in three groups of sizes to provide a wide dynamic range of radar cross-section measurements. Each test target in a group has the same physical area but differs in aperture shape. The aperture shape, aperture dimensions, and calculated peak radar cross section (at X-band frequency) of the six test targets used in the evaluation are shown below.

Square aperture targets:	Calculated RCS @ X-band
5.14 cm by 5.14 cm	-10 dBsm
9.13 cm by 9.13 cm	0 dBsm
25.3 cm by 25.3 cm	17 dBsm

Circular aperture targets:	
5.14 cm radius	0 dBsm
14.3 cm radius	17 dBsm

Rectangular aperture target:	
70 cm by 9.13 cm	17 dBsm

The test targets were fabricated from flat aluminum sheet; the three smaller targets were made of 3/32 inch thick material and the three larger targets of 1/8 inch thick material. A photograph of the six targets is shown in Figure 12.

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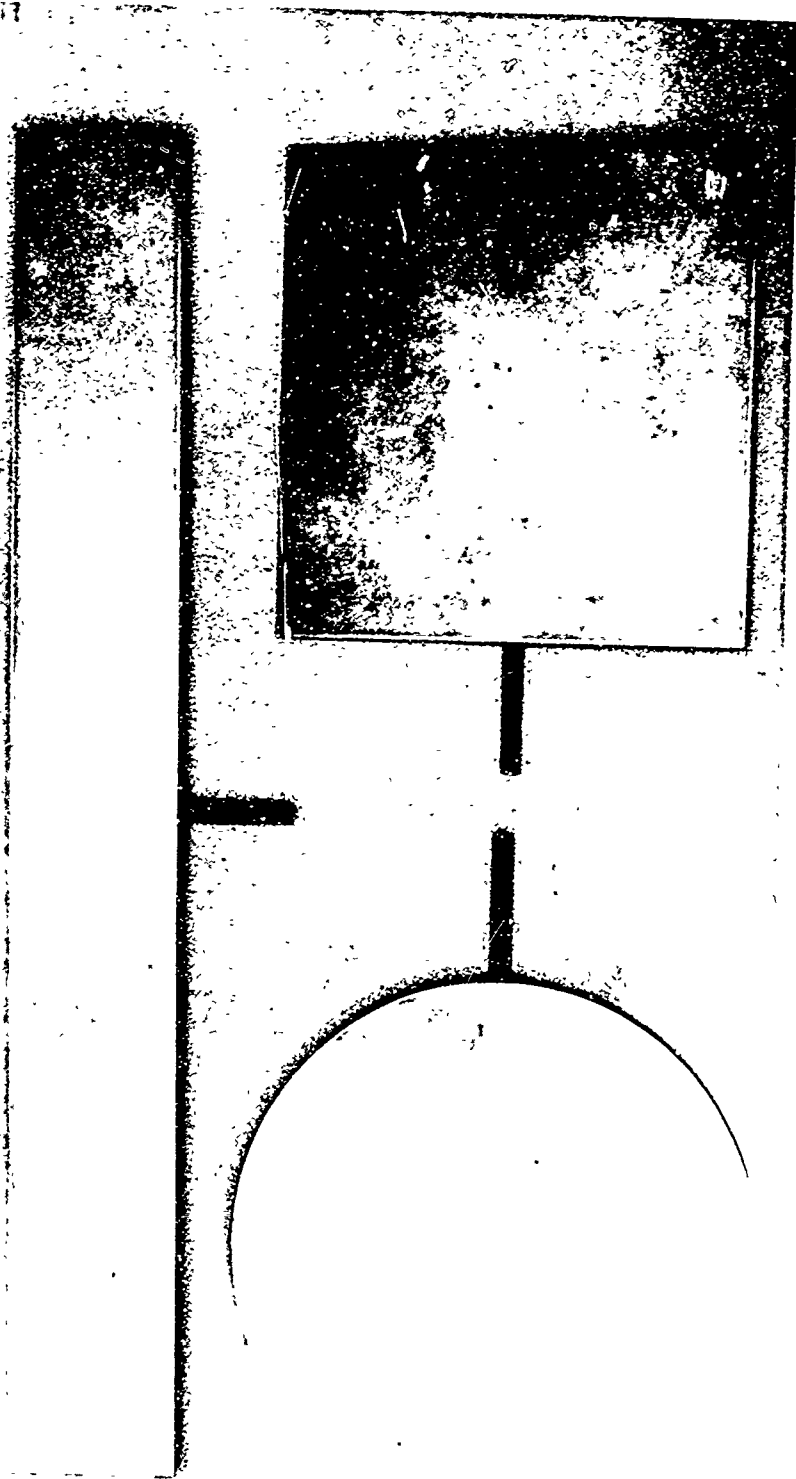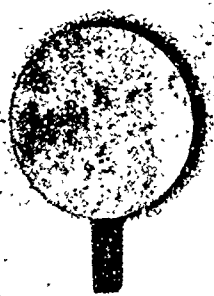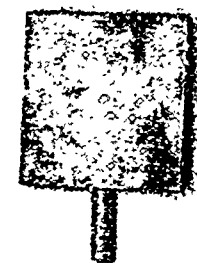
Figure 12. Photograph of the six flat plate test targets

C. Selected Military Targets

One of the prime advantages of a compact reflectivity range is the ease and speed in which complete reflectivity patterns of complex targets can be determined. To demonstrate this capability, radar reflectivity patterns of a small Claymore mine (M18A1) and a 50 caliber projectile were measured on the compact reflectivity ranges. Photographs of these two military targets are shown in Figure 13.

A Claymore anti-personnel mine with area approximately 8 inches by 4 inches was used for these measurements. The lethal radius for this mine is approximately 150 feet over an azimuthal dispersion angle of approximately 60 degrees. As can be seen in Figure 13, the small spherical projectiles in the mine produce the primary radar backscatter from this target.
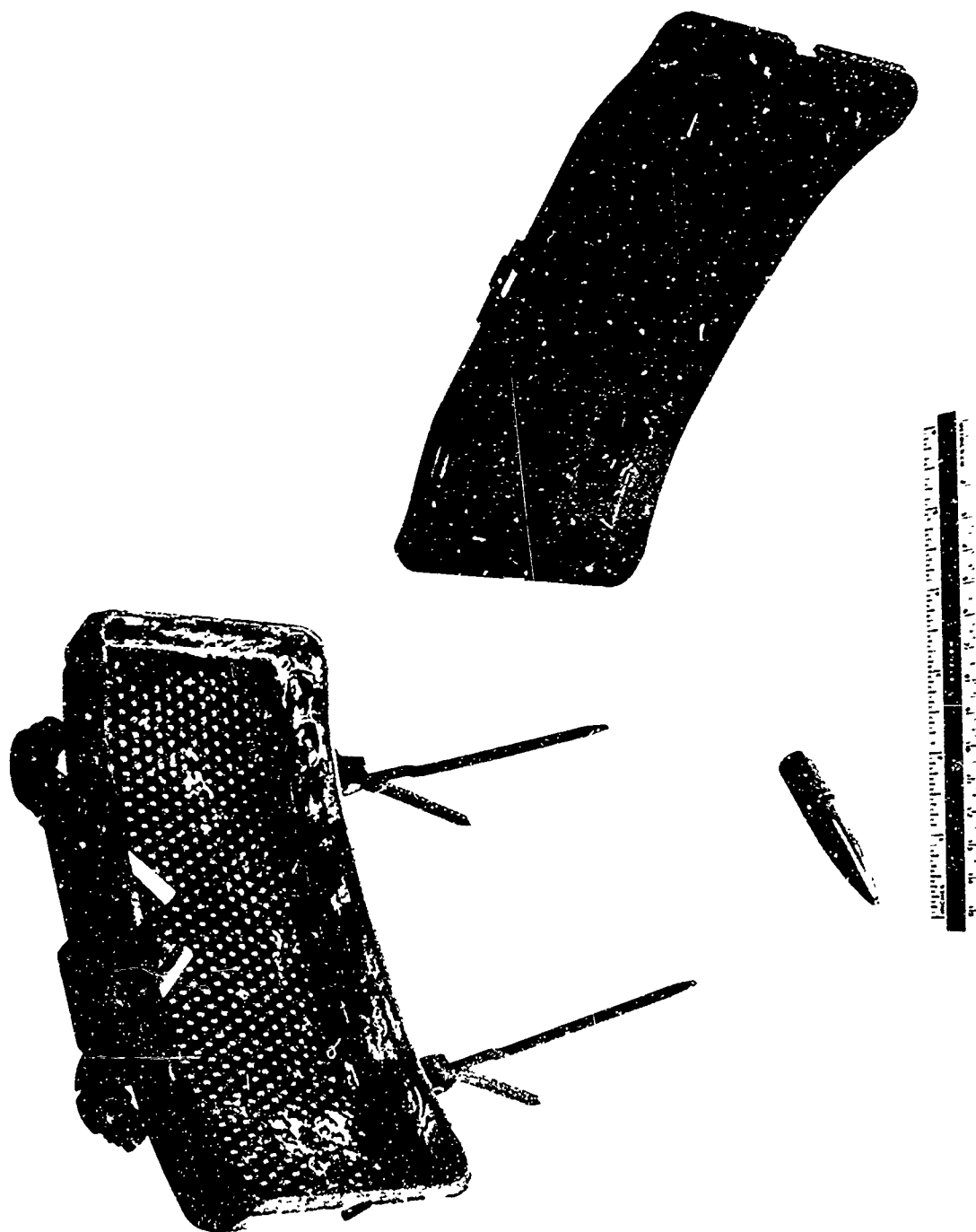
Figure 13. Photograph of the 50 caliber projectile and the Claymore mine, with back cover removed

SECTION V

EVALUATION OF REFLECTIVITY MEASUREMENTS ON THE COMPACT RANGES

A. Introduction

The backscatter patterns as a function of azimuth angle were measured

for each of the six flat plate test targets described in Section IV.

These data were measured on the line-source and the point-source compact

reflectivity ranges at frequencies of 8.2, 9.0, 9.4, 10.0, and 12.0 GHz.

Backscatter patterns also were recorded for several targets commonly

used with radar systems; e.g., a trihedral corner, a dihedral corner, and

a cylinder. These backscatter data were compared with their maximum

theoretical values of radar cross section computed from the geometrical

aperture areas and frequencies of operation. No attempt was made to

compare these data to theoretical backscatter patterns as a function of

aspect angle.

Several military targets, including a Claymore mine and a 50 caliber

projectile, were measured to investigate their backscatter characteristics.

These data were taken to demonstrate the practicality and usefulness of

the ranges since the computation of accurate theoretical values for these

targets is impractical, if not impossible.

B. Theoretical Backscatter Pattern Calculation

Theoretical backscatter patterns as a function of azimuth angle were

calculated for the six flat plate test targets described in Section IV.

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These calculations were performed on a Burroughs B-5500 digital computer with a program in ALGOL language. Separate computer programs were written for rectangular or square aperture targets and for circular aperture targets. The programs provide for variation of target size, frequency of operation, and azimuth angle relative to normal incidence.

The programmed equation for calculating the flat plate backscatter values for a rectangular or square aperture flat plate is

$$\sigma_r = \frac{64\pi a^2 b^2}{\lambda^2} \cos^2\Phi \left[\frac{\sin(2ka \sin \Phi)}{(2ka \sin \Phi)}\right]^2$$

where $k = 2\pi/\lambda$, 2a is width of target, 2b is height of target, Φ is the azimuth angle of rotation, and λ is the wavelength.

The equation used for the flat plate with a circular aperture is

$$\sigma_c = \left[\sqrt{\pi}\ \lambda\ r \cot \Phi\ J_1(4\pi\ r \sin \Phi)\right]^2$$

where λ and Φ are as defined above, r is the aperture radius, and J_1 is the first order Bessel function.

Data points of target radar cross section were obtained for 60 degrees of azimuth rotation, in 1/3 degree increments, for each of the six test targets and test frequencies of 8.2, 9.0, 9.4, 10.0, and 12.0 GHz. These data were plotted on the standard pattern recorder paper to provide the theoretical curves of the backscatter from these targets as a function

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of azimuth angle. The measured backscatter patterns were compared to these theoretical backscatter curves.

C. Measured Backscatter Patterns

Typical measured backscatter patterns of several flat plate test targets are presented in Figures 14 through 19. Figures 14 and 15 are backscatter patterns for ± 30 degrees of azimuth rotation of the 70 cm by 9.13 cm rectangular flat plate, measured on the line-source and the point-source compact reflectivity ranges at a measurement frequency of 10 GHz. Included in each figure is the calculated theoretical backscatter pattern for comparison. For the same set of conditions, Figures 16, 17, 18, and 19 are patterns of the 14.3 cm radius circular flat plate and 25.3 cm square flat plate measured on both ranges.

The measured backscatter patterns for 360 degrees of azimuth rotation of a dihedral corner are shown in Figure 20. This figure compares the backscatter pattern of the dihedral corner measured on the line-source and point-source compact reflectivity ranges at a measurement frequency of 10 GHz. This dihedral corner is fabricated from two rectangular flat plates having dimensions of 30.5 cm by 15.25 cm and oriented such that the intersection of the long sides forms an angle of 90 degrees. This target has a much broader main beamwidth in the azimuth direction than do the flat plate targets.

Figure 21 shows the measured backscatter patterns for 360 degrees of azimuth rotation of a Claymore mine and a 50 caliber projectile.

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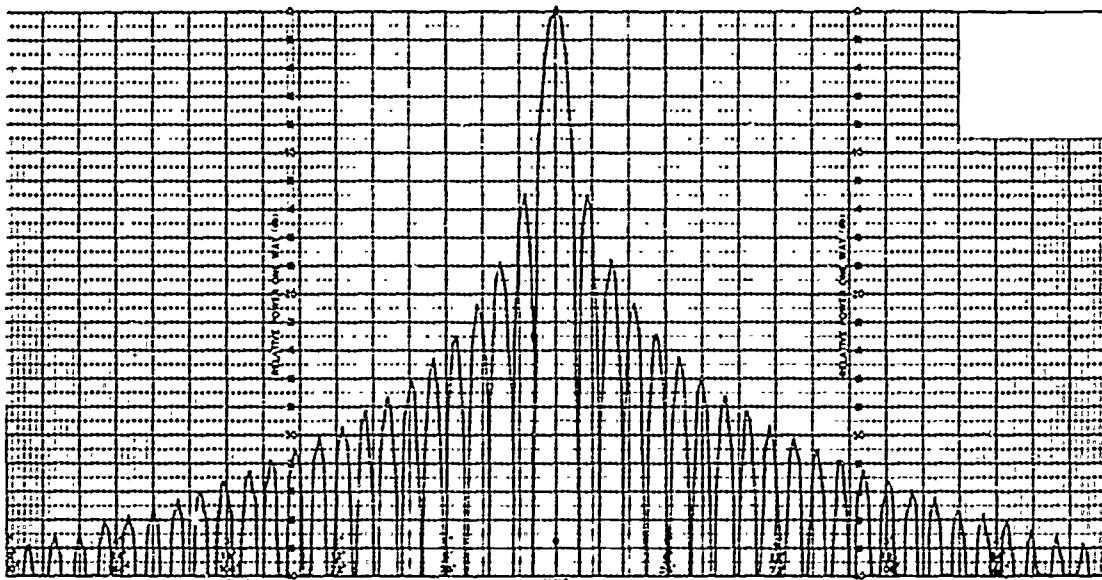
(a) Theoretical backscatter pattern
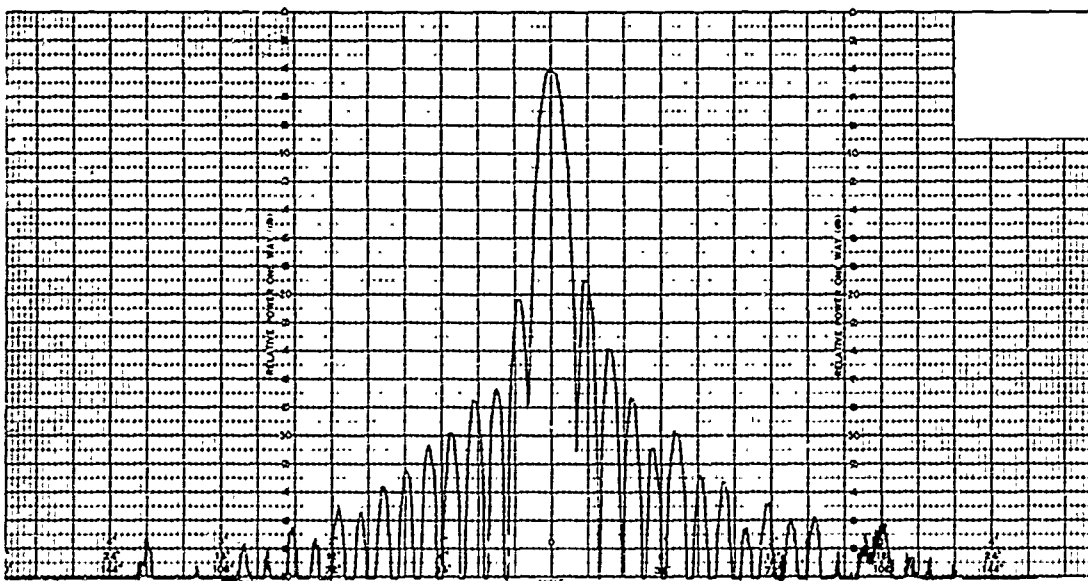
(b) Measured backscatter pattern

Figure 14.   Theoretical and measured backscatter patterns of a 70 cm by
9.13 cm flat plate. Measured pattern obtained on the compact
line-source range at 10 GHz.
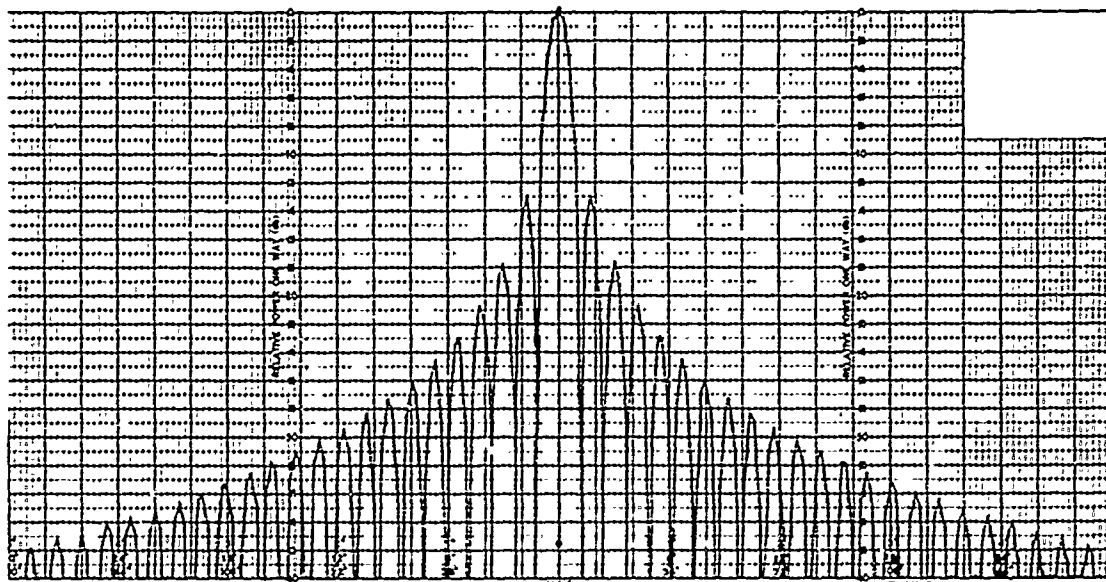
(a) Theoretical backscatter pattern
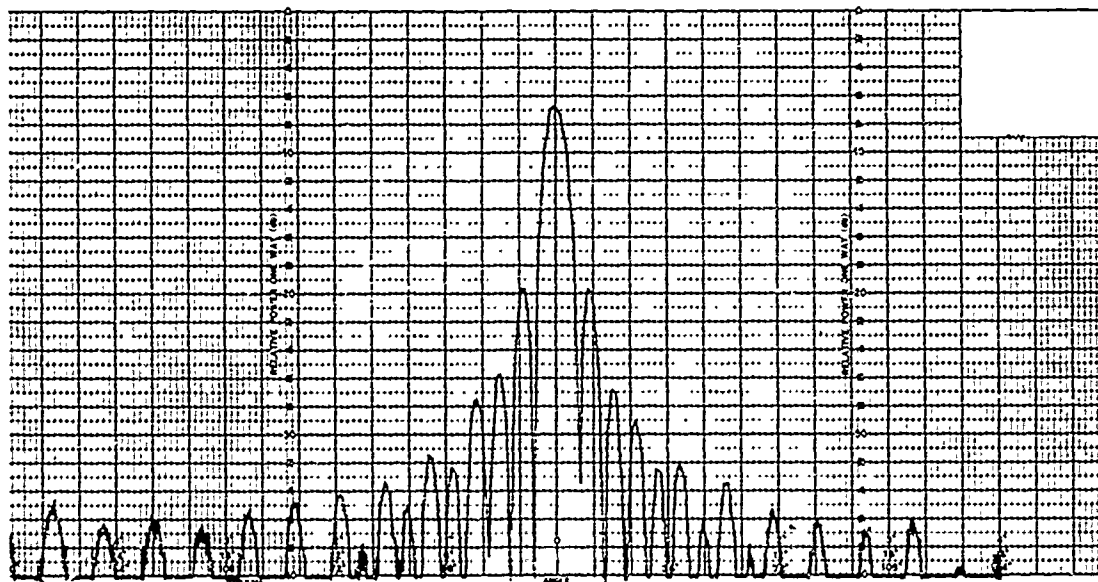
(b) Measured backscatter pattern

Figure 15. Theoretical and measured backscatter patterns of a 70 cm by
9.13 cm flat plate. Measured pattern obtained on the compact
point-source range at 10 GHz.

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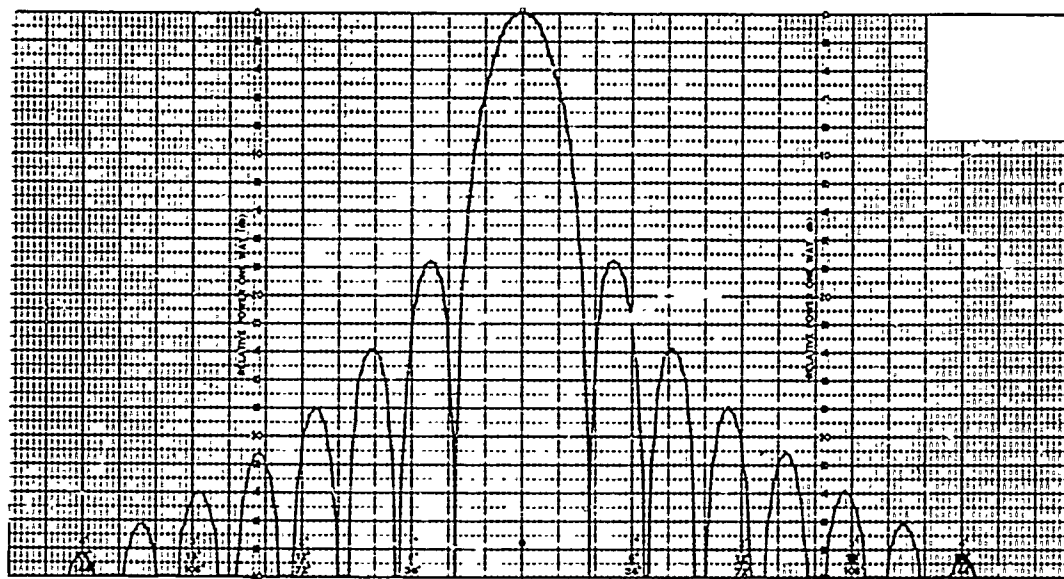
(a) Theoretical backscatter pattern
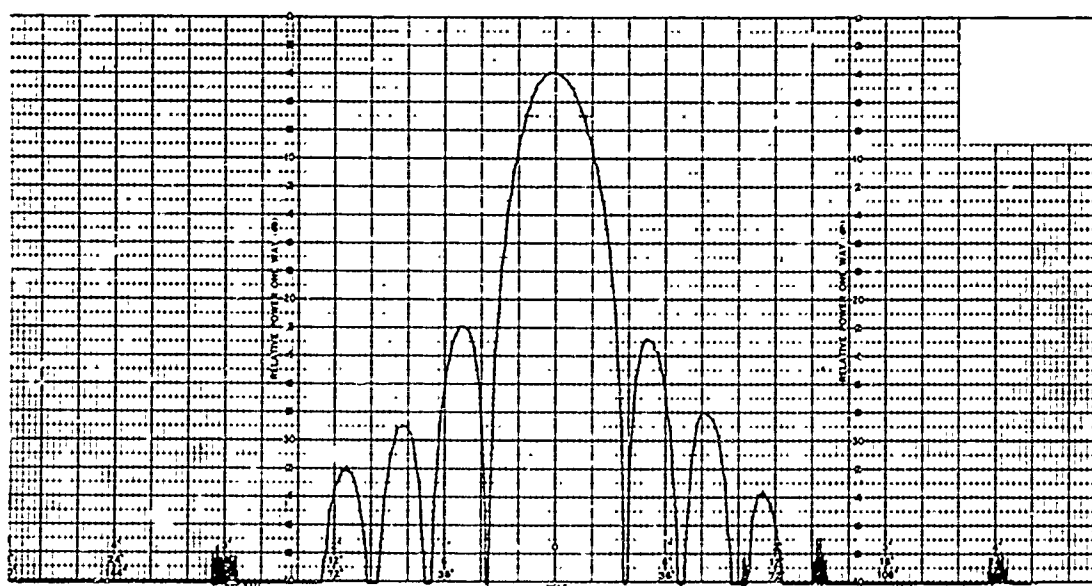
(b) Measured backscatter pattern

Figure 16. Theoretical and measured backscatter patterns of a 14.3 cm
radius circular flat plate. Measured pattern obtained on
the compact line-source range at 10 GHz.

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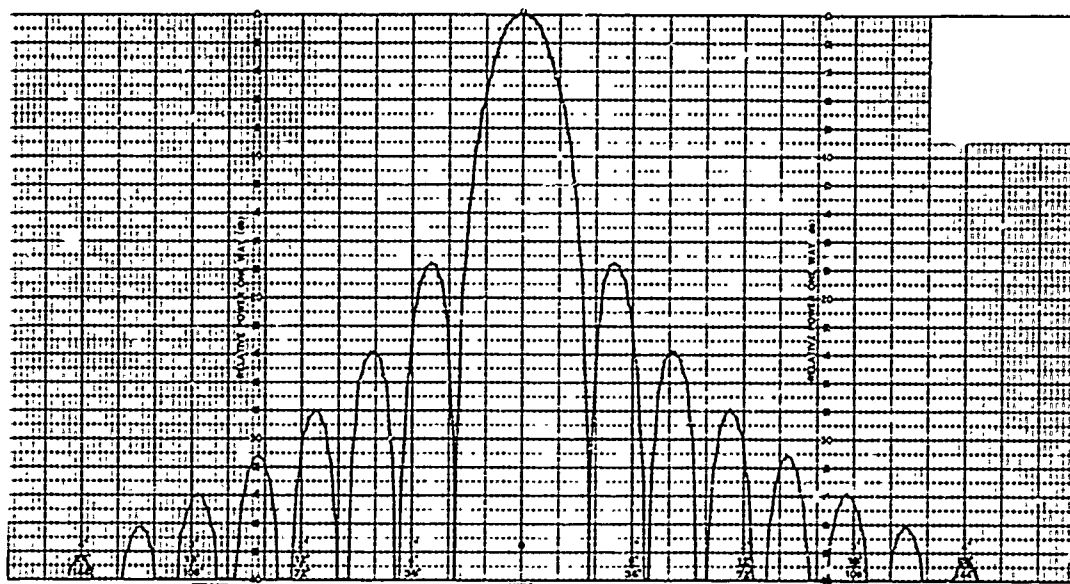
(a) Theoretical backscatter pattern
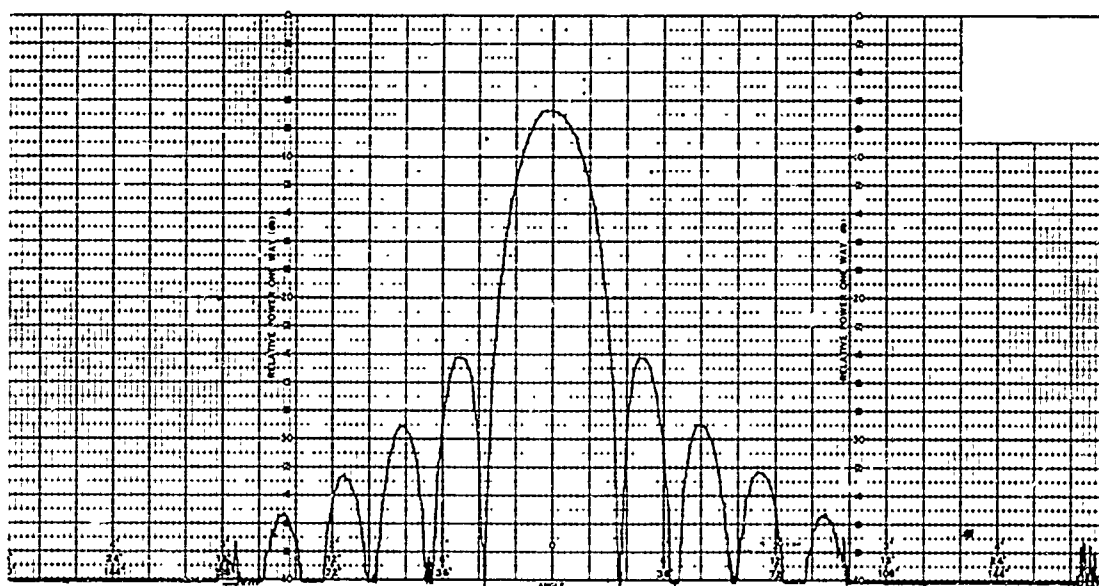
(b) Measured backscatter pattern

Figure 17.   Theoretical·and measured backscatter patterns of a 14.3 cm
              radius circular flat plate. Measured pattern obtained on
              the compact point-source range at 10 GHz.

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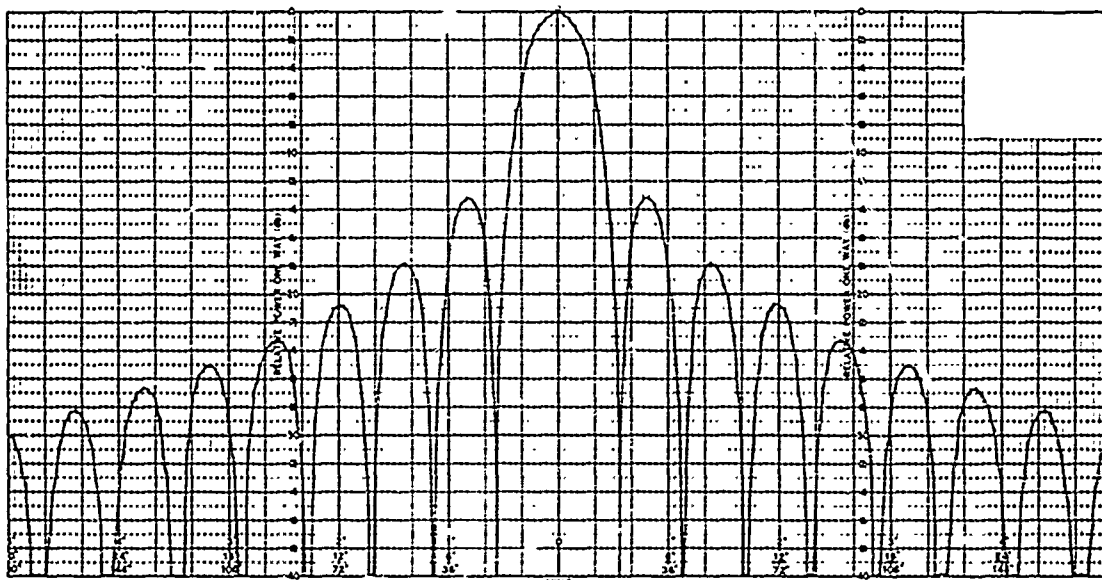
(a) Theoretical backscatter pattern
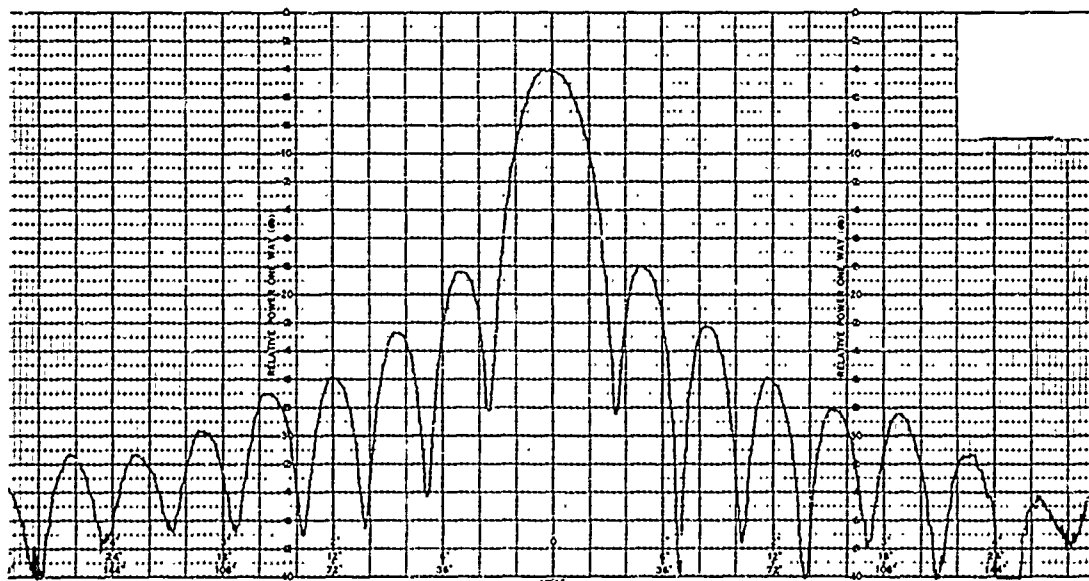
(b) Measured backscatter pattern

Figure 18.   Theoretical and measured backscatter patterns of a 25.3 cm
             by 25.3 cm flat plate. Measured pattern obtained on the
             compact line-source range at 10 GHz.
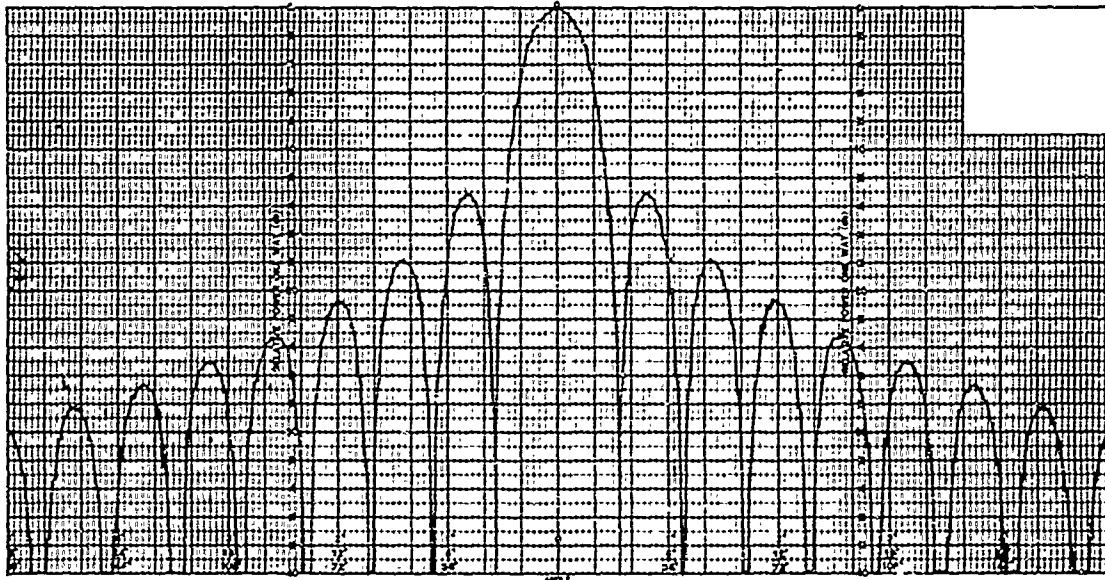
(a) Theoretical backscatter pattern
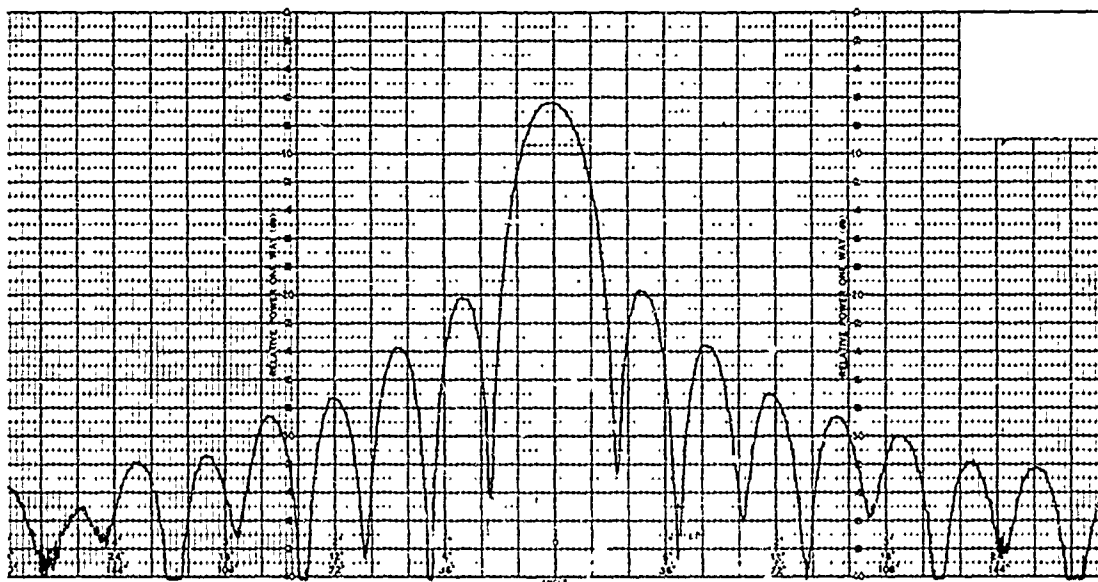
(b) Measured backscatter pattern

Figure 19.   Theoretical and measured backscatter patterns of a 25.3 cm
              by 25.3 cm flat plate. Measured pattern obtained on the
              compact point-source range at 10 GHz.
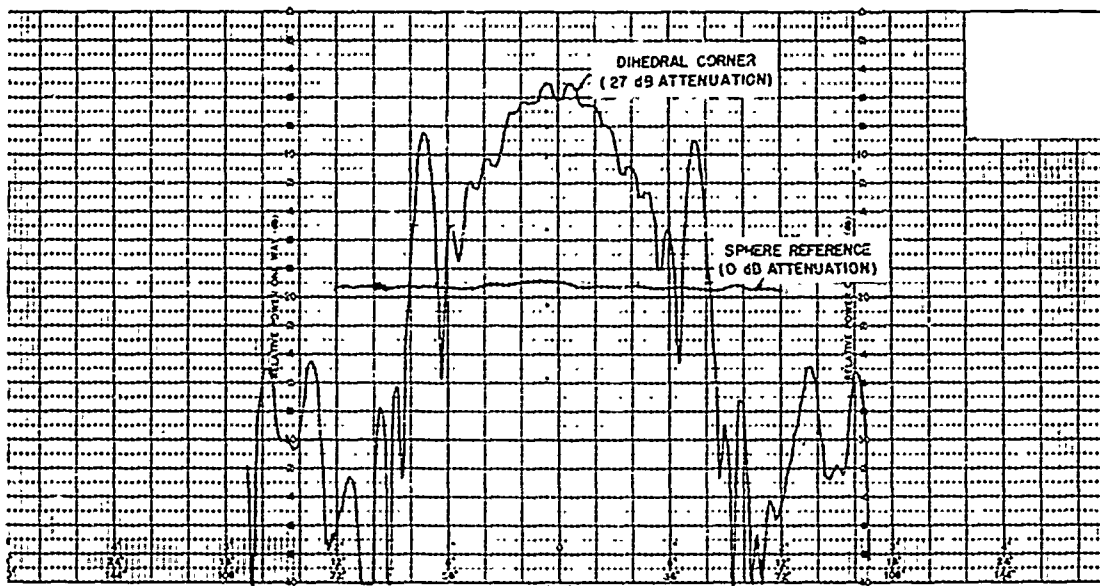
(a) Measured on line-source range
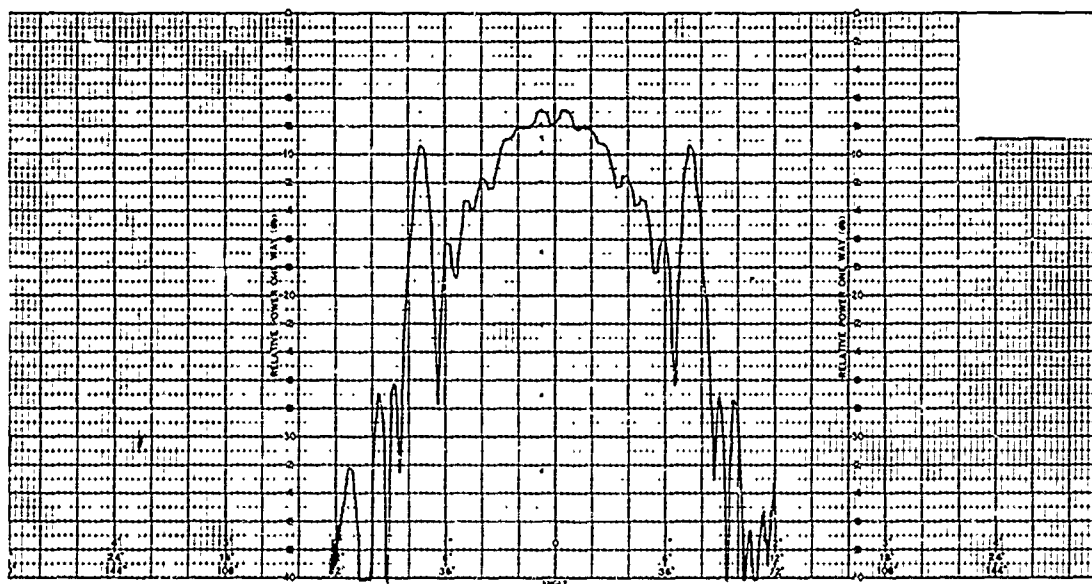
(b) Measured on point-source range

Figure 20. Backscatter patterns of a dihedral corner obtained on the compact line-source and compact point-source ranges at 10 GHz.
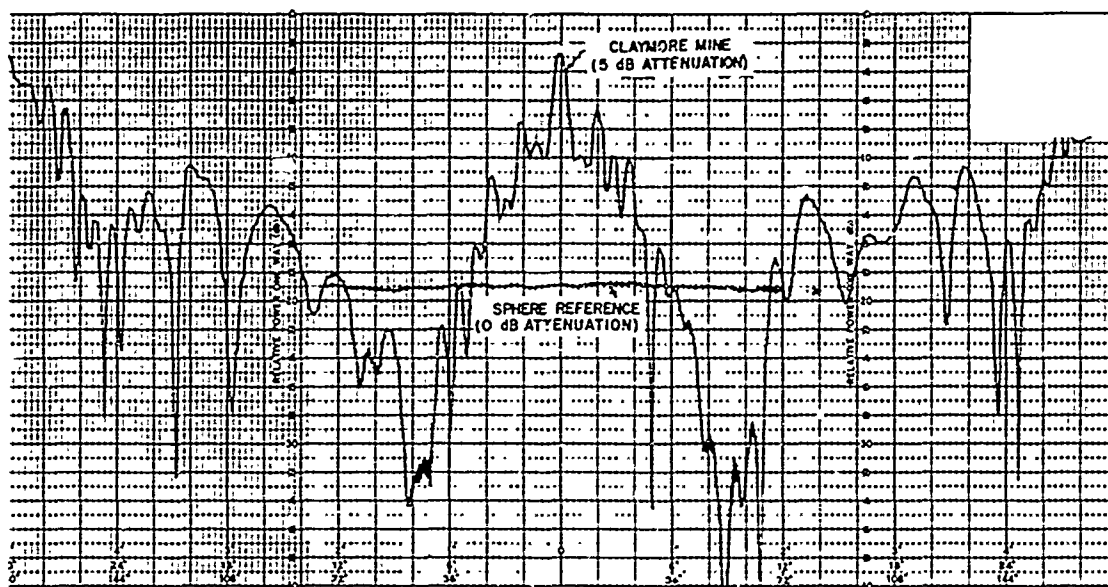
(a) Claymore mine (measured pattern has 5 dB attenuation relative to indicated sphere reference)
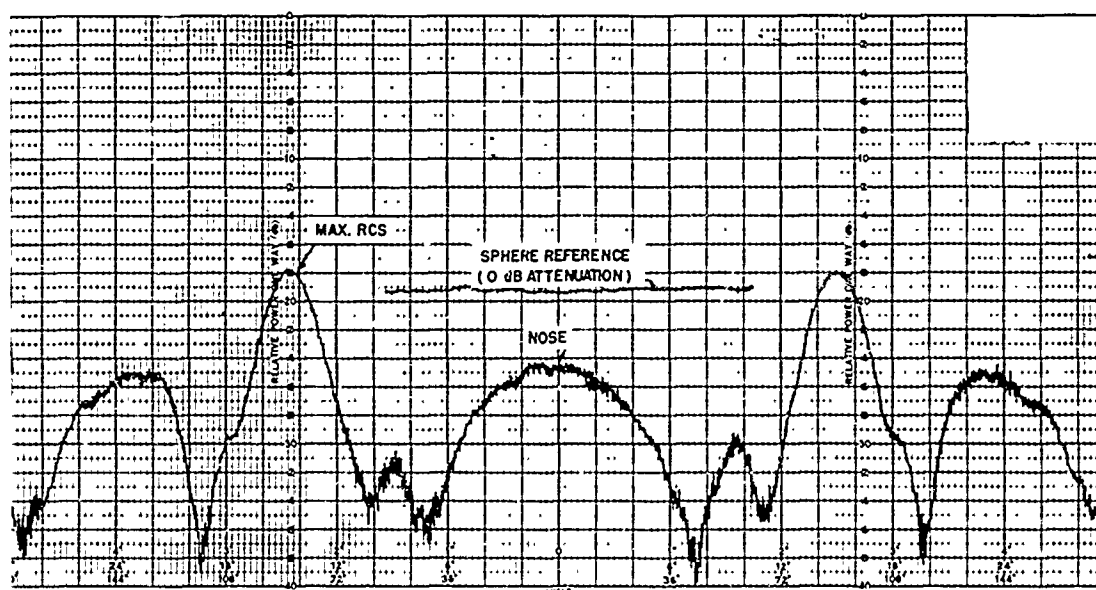
(b) 50 caliber projectile

Figure 21. F.. scatter patterns of a Claymore mine and a 50 caliber projectile, obtained on the compact line-source range at 10 GHz. Indicated RCS of sphere reference is -26.1 dBsm.

These measured data were obtained at a frequency of 10 GHz on the line-source compact reflectivity range. The backscatter pattern of the Claymore mine, Figure 21-a, has a 5 dB of attenuation relative to 0 dB attenuation for the indicated sphere reference; thus the measured peak radar cross section (RCS) of this Claymore mine is -5 dBsm. For the backscatter pattern of the 50 caliber projectile, Figure 21-b, the projectile was positioned with its longitudinal axis horizontal. The signal levels for the projectile and reference sphere may be compared directly. As indicated, the measured peak RCS* of the projectile occurs for a broadside orientation of the projectile and has a value of -25 dBsm.

D. Comparison of Results

The measured backscatter patterns as a function of azimuth angle were compared to the calculated backscatter patterns in detail at the following points:

1) peak radar cross section (RCS),

2) half-power beamwidth,

3) azimuth displacement of 1st and 2nd nulls,

4) depth of 1st and 2nd nulls, relative to maximum RCS, and

5) amplitude of 1st and 2nd side-lobes relative to maximum RCS.

This method of data analysis provides an indication of the phase and amplitude illumination across the target aperture. For example, if the phase distribution across the flat plate aperture is not uniform,

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*In this report RCS is used for radar cross section.

broadening of the main lobe and filling in of the null regions occur. This effect becomes evident for phase errors exceeding $\pi/16$ radians. If the amplitude distribution across the flat plate aperture is not constant, the effect is to produce an error in the measurement of peak radar cross section, a reduction of the side-lobe amplitude relative to the main lobe, and a shift in angular position of the nulls.

The data presented in tabular form in Tables I through XII are a comparison of the measured and calculated values of peak RCS, half-power beamwidth, null and side-lobe levels[*], and null angular displacement. It may be noted that data for the 5.14 cm square aperture flat plate is not presented for the 2nd null and 2nd side-lobe points. These data occurred at azimuth angles greater than 30 degrees and therefore do not allow a valid comparison of theoretical and measured data using the physical optics method of analysis. Also, several data points for the measured data obtained on the point-source range are omitted. Equipment failures during measurements invalidated these portions of the data measured on the point-source range.

Analysis of the data shows very good agreement between the measurements of backscatter patterns taken on both the line-source and point-source compact reflectivity ranges and the theoretically calculated backscatter patterns. The main deviation of the measured data from the theoretical values occurs in the comparison of peak radar cross section for the large targets. For the smaller test targets, the measured value

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[*] Null levels presented in data are the worst case; side-lobe levels relative to the peak RCS are an average of the symmetrical lobes, with ± 1 dB the worst case of asymmetry.

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TABLE I

COMPARISON OF MEASURED AND THEORETICAL RCS DATA
ON THE 70 cm BY 9.13 cm FLAT PLATE
FOR THE COMPACT LINE-SOURCE REFLECTIVITY RANGE

ITEM	FREQ~GHz	8.2	9.0	9.4	10.0	2.0
SPHERE REF. (dBSM)	CAL.	-26.2	-24.0	-24.6	-26.1	-26.0
PEAK RCS (dBSM)	MEAS.	15.0	14.5	15.4	16.0	15.7
	CAL.	16.1	16.8	17.0	17.5	18.9
-3 dB B.W. (DEGREES)	MEAS.	1.33°	1.30°	1.30°	1.10°	1.00°
	CAL.	1.50°	1.20°	1.15°	1.15°	1.00°
1st NULL (DEGREES)	MEAS.	1.50°	1.40°	1.38°	1.33°	1.33°
	CAL.	1.60°	1.33°	1.32°	1.25°	1.10°
1st NULL LEVEL (dB)	MEAS.	-24.0	-24.0	-23.0	-24.0	-23.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
1st S.L. LEVEL (dB)	MEAS.	-14.8	-15.5	-15.0	-15.5	-15.3
	CAL.	-13.2	-13.2	-13.2	-13.2	-13.2
2nd NULL (DEGREES)	MEAS.	3.00°	2.80°	2.67°	2.70°	2.67°
	CAL.	3.00°	2.67°	2.60°	2.33°	2.10°
2nd NULL LEVEL (dB)	MEAS.	-30.0	<-36.0	<-38.0	<-36.0	<-35.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
2nd S.L. LEVEL (dB)	MEAS.	-19.5	-19.5	-20.0	-21.0	-20.2
	CAL.	-17.6	-17.6	-17.6	-17.6	-17.6

TABLE II

COMPARISON OF MEASURED AND THEORETICAL RCS DATA
ON THE 25.3 cm BY 25.3 cm FLAT PLATE
FOR THE COMPACT LINE-SOURCE REFLECTIVITY RANGE

ITEM \ FREQ.~GHz		8.2	9.0	9.4	10.0	12.0
SPHERE REF. (dBSM)	CAL.	-26.2	-24.0	-24.6	-26.1	-26.0
PEAK RCS (dBSM)	MEAS.	14.3	14.7	15.4	16.4	17.1
	CAL.	15.8	16.6	16.7	17.4	19.0
-3 dB B.W. (DEGREES)	MEAS.	3.67°	3.33°	3.20°	3.10°	2.40°
	CAL.	3.90°	3.60°	3.50°	3.20°	2.50°
1st NULL (DEGREES)	MEAS.	4.20°	3.70°	3.60°	3.50°	2.67°
	CAL.	4.15°	3.67°	3.60°	3.33°	2.80°
1st NULL LEVEL (dB)	MEAS.	-26.0	-27.0	-26.0	-24.0	-24.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
1st S.L. LEVEL (dB)	MEAS.	-13.8	-14.2	-13.5	-14.0	-14.5
	CAL.	-13.2	-13.2	-13.2	-13.2	-13.2
2nd NULL (DEGREES)	MEAS.	8.50°	7.50°	7.20°	6.80°	5.80°
	CAL.	8.33°	7.67°	7.33°	6.80°	5.67°
2nd NULL LEVEL (dB)	MEAS.	-27.0	-27.5	-22.0	-32.0	<-35.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
2nd S.L. LEVEL (dB)	MEAS.	-19.5	-18.0	-18.0	-18.5	-18.2
	CAL.	-17.6	-17.6	-17.6	-17.6	-17.6

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TABLE III

COMPARISON OF MEASURED AND THEORETICAL RCS DATA
ON THE 14.3 cm RADIUS FLAT PLATE
FOR THE COMPACT LINE-SOURCE REFLECTIVITY RANGE

FREQ.~GHz / ITEM		8.2	9.0	9.4	10.0	12.0
SPHERE REF. (dBSM)	CAL.	-20.2	-24.0	-24.6	-26.1	-26.0
PEAK RCS (dBSM)	MEAS.	15.3	13.5	15.2	16.4	17.0
	CAL.	15.8	16.5	16.7	17.3	18.9
-3 dB B.W. (DEGREES)	MEAS.	3.85°	3.60°	3.50°	3.10°	2.50°
	CAL.	4.00°	3.50°	3.40°	3.10°	2.80°
1st NULL (DEGREES)	MEAS.	4.50°	4.20°	4.00°	3.70°	3.10°
	CAL.	4.40°	4.15°	4.00°	3.60°	3.10°
1st NULL LEVEL (dB)	MEAS.	<-34.0	<-36.0	<-34.0	<-36.0	-35.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
1st S.L. LEVEL (dB)	MEAS.	-18.5	-19.0	-18.0	-18.5	-18.2
	CAL.	-17.6	-17.6	-17.6	-17.6	-17.6
2nd NULL (DEGREES)	MEAS.	8.50°	7.50°	7.33°	6.80°	5.67°
	CAL.	8.15°	7.50°	7.33°	6.60°	5.60°
2nd NULL LEVEL (dB)	MEAS.	-31.0	<-40.0	<-40.0	<-40.0	<-40.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
2nd S.L. LEVEL (dB)	MEAS.	-25.5	-22.3	-24.5	-24.5	-24.0
	CAL.	-24.0	-24.0	-24.0	-24.0	-24.0

TABLE IV

COMPARISON OF MEASURED AND THEORETICAL RCS DATA
ON THE 9.13 cm BY 9.13 cm FLAT PLATE
FOR THE COMPACT LINE-SOURCE REFLECTIVITY RANGE

FREQ.~GHz ITEM		8.2	9.0	9.4	10.0	12.0
SPHERE REF. (dBSM)	CAL.	-26.2	-24.0	-24.6	-26.1	-26.0
PEAK RCS (dBSM)	MEAS.	- 1.2	- 2.0	- 0.6	- 0.6	0.0
	CAL.	- 1.9	- 1.1	- 0.9	- 0.2	$\div$ 1.4
-3 dB B.W. (DEGREES)	MEAS.	10.40°	9.50°	8.80°	8.70°	7.00°
	CAL.	10.30°	9.50°	9.20°	8.30°	6.90°
1st NULL (DEGREES)	MEAS.	11.30°	10.67°	10.33°	9.33°	7.80°
	CAL.	11.67°	10.50°	10.33°	9.50°	8.00°
1st NULL LEVEL (dB)	MEAS.	-22.0	-23.0	-20.0	-24.0	-25.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
1st S.L. LEVEL (dB)	MEAS.	-13.4	-13.2	-14.0	-12.8	-13.1
	CAL.	-13.2	-13.2	-13.2	-13.2	-13.2
2nd NULL (DEGREES)	MEAS.	23.00°	21.30°	20.00°	19.30°	15.80°
	CAL.	23.80°	21.30°	20.80°	19.20°	16.00°
2nd NULL LEVEL (dB)	MEAS.	-26.0	-22.0	-28.0	-22.0	-25.5
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
2nd S.L. LEVEL (dB)	MEAS.	-17.5	-17.8	-17.0	-18.0	-17.9
	CAL.	-17.6	-17.6	-17.6	-17.6	-17.6

TABLE V

COMPARISON OF MEASURED AND THEORETICAL RCS DATA
ON THE 5.14 cm RADIUS FLAT PLATE
FOR THE COMPACT LINE-SOURCE REFLECTIVITY RANGE

FREQ.~GHz / ITEM		8.2	9.0	9.4	10.0	12.0
SPHERE REF. (dBSM)	CAL.	-26.2	-24.0	-24.6	-26.1	-26.0
PEAK RCS (dBSM)	MEAS.	- 1.7	- 2.0	- 0.6	- 0.8	+ 0.2
	CAL.	- 1.9	- 1.1	- 0.9	- 0.2	+ 1.4
-3 dB B.W. (DEGREES)	MEAS.	10.90°	9.80°	9.33°	8.50°	7.00°
	CAL.	10.50°	9.67°	9.20°	8.75°	7.20°
1st NULL (DEGREES)	MEAS.	13.00°	11.50°	10.80°	10.80°	8.50°
	CAL.	12.50°	11.33°	11.00°	10.30°	8.67°
1st NULL LEVEL (dB)	MEAS.	-28.0	-29.0	-25.0	-27.0	-29.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
1st S.L. LEVEL (dB)	MEAS.	-19.5	-17.5	-17.0	-17.6	-17.5
	CAL.	-17.6	-17.6	-17.6	-17.6	-17.6
2nd NULL (DEGREES)	MEAS.	23.50°	21.50°	20.50°	18.70°	15.50°
	CAL.	23.40°	21.20°	20.70°	19.00°	16.00°
2nd NULL LEVEL (dB)	MEAS.	-28.0	-32.0	<40	<-36.0	-32.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
2nd S.L. LEVEL (dB)	MEAS.	-25.0	-24.5	-24.0	-22.5	-23.5
	CAL.	-24.0	-24.0	-24.0	-24.0	-24.0

TABLE VI

COMPARISON OF MEASURED AND THEORETICAL RCS DATA
ON THE 5.14 cm BY 5.14 cm FLAT PLATE
FOR THE COMPACT LINE-SOURCE REFLECTIVITY RANGE

ITEM / FREQ~GHz		8.2	9.0	9.4	10.0	12.0
SPHERE REF. (dBSM)	CAL.	-26.2	-24.0	-24.6	-26.1	-26.0
PEAK RCS (dBSM)	MEAS.	-11.0	-11.2	-10.3	-10.1	- 9.0
	CAL.	-11.9	-11.0	-10.8	-10.1	- 8.5
-3 dB B.W. (DEGREES)	MEAS.	18.00°	16.00°	16.00°	14.00°	12.60°
	CAL.	19.00°	17.00°	16.50°	15.00°	12.50°
1st NULL (DEGREES)	MEAS.	20.50°	18.00°	17.00°	17.00°	15.00°
	CAL.	21.00°	19.00°	18.50°	17.00°	14.00°
1st NULL LEVEL (dB)	MEAS.	-24.0	-17.0	-13.0	-18.0	-21.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
1st S.L. LEVEL (dB)	MEAS.	-13.3	-12.7	-13.3	-13.5	-13.5
	CAL.	-13.2	-13.2	-13.2	-13.2	-13.2
2nd NULL (DEGREES)	MEAS.					
	CAL.					
2nd NULL LEVEL (dB)	MEAS.					
	CAL.					
2nd S.L. LEVEL (dB)	MEAS.					
	CAL.					

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TABLE VII

COMPARISON OF MEASURED AND THEORETICAL RCS DATA
ON THE 70 cm BY 9.13 cm FLAT PLATE
FOR THE COMPACT POINT-SOURCE REFLECTIVITY RANGE

FREQ.~GHz ITEM		8.2	9.0	9.4	10.0	12.0
SPHERE REF. (dBSM)	CAL.	-26.2	-24.0	-24.6	-26.1	-26.0
PEAK RCS (dB SM)	MEAS.	14.1	15.0	15.0	13.9	16.8
	CAL.	16.1	16.8	17.0	17.5	18.9
-3 dB B.W. (DEGREES)	MEAS.	1.35°	1.30°	1.25°	1.16°	1.00°
	CAL.	1.50°	1.20°	1.15°	1.15°	1.00°
1st NULL (DEGREES)	MEAS.	1.67°	1.40°	1.35°	1.30°	1.05°
	CAL.	1.60°	1.33°	1.32°	1.25°	1.10°
1st NULL LEVEL (dB)	MEAS.	-30.0	-29.0	-23.0	-27.0	-20.0 -28.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
1st S.L. LEVEL (dB)	MEAS.	-16.0	-15.5	-15.0	-12.9	-13.5
	CAL.	-13.2	-13.2	-13.2	-13.2	-13.2
2nd NULL (DEGREES)	MEAS.	3.00°	2.70°	2.60°	2.60°	2.15°
	CAL.	3.00°	2.67°	2.60°	2.33°	2.10°
2nd NULL LEVEL (dB)	MEAS.	<-30.0	<-30.0	-32.0	-33.0	-28.0 -36.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
2nd S.L. LEVEL (dB)	MEAS.	-18.0	-17.5	-17.0	-19.5	-21.0
	CAL.	-17.6	-17.6	-17.6	-17.6	-17.6

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TABLE VIII

COMPARISON OF MEASURED AND THEORETICAL RCS DATA
ON THE 25.3 cm BY 25.3 cm FLAT PLATE
FOR THE COMPACT POINT-SOURCE REFLECTIVITY RANGE

ITEM / FREQ.~GHz		8.2	9.0	9.4	10.0	12.0
SPHERE REF. (dBSM)	CAL.	-26.2	-24.0	-24.6	-26.1	-26.0
PEAK RCS (dB SM)	MEAS.	14.3	14.8	14.7	14.4	17.0
	CAL.	15.8	16.6	16.7	17.4	19.0
-3 dB B.W. (DEGREES)	MEAS.	$3.83°$	$3.33°$	$3.40°$	$3.15°$	$2.50°$
	CAL.	$3.90°$	$3.60°$	$3.50°$	$3.20°$	$2.50°$
1st NULL (DEGREES)	MEAS.	$4.20°$	$3.60°$	$3.60°$	$3.40°$	$2.80°$
	CAL.	$4.15°$	$3.67°$	$3.60°$	$3.33°$	$2.80°$
1st NULL LEVEL (dB)	MEAS.	-27.0	-30.0	-27.0	-26.0	-23.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
1st S.L. LEVEL (dB)	MEAS.	-13.2	-12.0	-13.3	-13.5	-13.2
	CAL.	-13.2	-13.2	-13.2	-13.2	-13.2
2nd NULL (DEGREES)	MEAS.	$8.30°$	$7.95°$	$7.30°$	$6.70°$	$5.65°$
	CAL.	$8.33°$	$7.67°$	$7.33°$	$6.80°$	$5.67°$
2nd NULL LEVEL (dB)	MEAS.	<-32.0	-25.0	<-34.0	-33.0	-29.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
2nd S.L. LEVEL (dB)	MEAS.	-18.1	-20.0	-17.9	-17.5	-17.5
	CAL.	-17.6	-17.6	-17.6	-17.6	-17.6

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TABLE IX

COMPARISON OF MEASURED AND THEORETICAL RCS DATA
ON THE 14.3 cm RADIUS FLAT PLATE
FOR THE COMPACT POINT-SOURCE REFLECTIVITY RANGE

ITEM	FREQ.~GHz	8.2	9.0	9.4	10.0	12.0
SPHERE REF. (dBSM)	CAL.	-26.2	-24.0	-24.6	-26.1	-26.0
PEAK RCS (dB SM)	MEAS.	13.8	15.0	14.7	13.9	16.9
	CAL.	15.8	16.5	16.7	17.3	18.9
-3 dB B.W. (DEGREES)	MEAS.	3.82°	3.50°	3.40°	3.16°	2.60°
	CAL.	4.00°	3.50°	3.40°	3.10°	2.80°
1st NULL (DEGREES)	MEAS.	4.50°	4.20°	3.80°	3.60°	3.05°
	CAL.	4.40°	4.15°	4.00°	3.60°	3.10°
1st NULL LEVEL (dB)	MEAS.	<-30.0	<-30.0	-30.0	-33.0	-30.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
1st S.L. LEVEL (dB)	MEAS.	-17.5	-17.5	-17.0	-17.5	-17.2
	CAL.	-17.6	-17.6	-17.6	-17.6	-17.6
2nd NULL (DEGREES)	MEAS.	8.60°	7.60°	7.30°	6.65°	5.60°
	CAL.	8.15°	7.50°	7.33°	6.60°	5.60°
2nd NULL LEVEL (dB)	MEAS.	<-35.0	<-30.0	<-35.0	<-34.0	-36.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
2nd S.L. LEVEL (dB)	MEAS.	-24.5	25.0	-24.0	-22.0	-24.0
	CAL.	-24.0	-24.0	-24.0	-24.0	-24.0

TABLE X

COMPARISON OF MEASURED AND THEORETICAL RCS DATA
ON THE 9.13 cm BY 9.13 cm FLAT PLATE
FOR THE COMPACT POINT-SOURCE REFLECTIVITY RANGE

ITEM	FREQ.~GHz	8.2	9.0	9.4	10.0	12.0
SPHERE REF. (dBSM)	CAL.	-26.2	-24.0	-24.6	-26.1	-26.0
PEAK RCS (dBSM)	MEAS.	- 2.2	- 1.5	- 1.8	- 1.6	- 0.8
	CAL.	- 1.9	- 1.1	- 0.9	- 0.2	+ 1.4
-3 dB B.W. (DEGREES)	MEAS.	10.00°	9.67°	9.70°	9.33°	7.00°
	CAL.	10.30°	9.50°	9.20°	8.30°	6.90°
1st NULL (DEGREES)	MEAS.	11.00°	11.00°	--	12.00°	7.70°
	CAL.	11.67°	10.50°	10.33°	9.50°	8.00°
1st NULL LEVEL (dB)	MEAS.	-24.0	-22.0	--	-30.0	-23.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
1st S.L. LEVEL (dB)	MEAS.	-11.5	-14.0	--	-11.3	-12.0
	CAL.	-13.2	-13.2	-13.2	-13.2	-13.2
2nd NULL (DEGREES)	MEAS.	23.00°	20.00°	--	18.00°	14.00°
	CAL.	23.80°	21.30°	20.80°	19.20°	16.00°
2nd NULL LEVEL (dB)	MEAS.	-18.0	-21.0	--	-22.0	-26.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
2nd S.L. LEVEL (dB)	MEAS.	-15.0	-14.5	--	-13.0	-18.5
	CAL.	-17.6	-17.6	-17.6	-17.6	-17.6

TABLE XI

COMPARISON OF MEASURED AND THEORETICAL RCS DATA
ON THE 5.14 cm RADIUS FLAT PLATE
FOR THE COMPACT POINT-SOURCE REFLECTIVITY RANGE

ITEM	FREQ~GHz	8.2	9.0	9.4	10.0	12.0
SPHERE REF. (dBSM)	CAL.	-26.2	-24.0	-24.6	-26.1	-26.0
PEAK RCS (dBSM)	MEAS.	-2.2	-1.5	-1.8	-3.8	-0.5
	CAL.	-1.9	-1.1	-0.9	-0.2	÷1.4
-3 dB B.W. (DEGREES)	MEAS.	11.00°	9.67°	9.00°	8.80°	7.30°
	CAL.	10.50°	9.67°	9.20°	8.75°	7.20°
1st NULL (DEGREES)	MEAS.	--	11.00°	10.50°	10.50°	8.40°
	CAL.	12.50°	11.33°	11.00°	10.30°	8.67°
1st NULL LEVEL (dB)	MEAS.	--	-30.0	-20.0	-25.0	-24.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
1st S.L. LEVEL (dB)	MEAS.	--	-16.8	-16.5	-18.3	-16.8
	CAL.	-17.6	-17.6	-17.6	-17.6	-17.6
2nd NULL (DEGREES)	MEAS.	--	21.00°	20.00°	19.00°	15.90°
	CAL.	-23.40°	21.20°	20.70°	19.00°	16.00°
2nd NULL LEVEL (dB)	MEAS.	--	-21.5	-30.0	-26.0	-32.0
	CAL.	-40.0	<-40.0	<-40.0	<-40.0	<-40.0
2nd S.L. LEVEL (dB)	MEAS.	--	-19.5	-21.0	-20.5	-20.6
	CAL.	-24.0	-24.0	-24.0	-24.0	-24.0

TABLE XII

COMPARISON OF MEASURED AND THEORETICAL RCS DATA
ON THE 5.14 cm BY 5.14 cm FLAT PLATE
FOR THE COMPACT POINT-SOURCE REFLECTIVITY RANGE

ITEM \ FREQ.~GHz		8.2	9.0	9.4	10.0	12.0
SPHERE REF. (dBSM)	CAL.	-26.2	-24.0	-24.6	-26.1	-26.0
PEAK RCS (dB SM)	MEAS.	-10.7	-10.7	- 9.8	-13.6	- 9.5
	CAL.	-11.9	-11.0	-10.8	-10.1	- 8.5
-3 dB B.W. (DEGREES)	MEAS.	18.5C°	17.20°	16.50°	14.00°	13.00°
	CAL.	19.00°	17.00°	16.50°	15.00°	12.50°
1st NULL (DEGREES)	MEAS.	21.00°	19.00°	--	--	14.50°
	CAL.	21.00°	19.00°	18.50°	17.00°	14.00°
1st NULL LEVEL (dB)	MEAS.	-16.0	-19.0	--	--	-20.0
	CAL.	<-40.0	<-40.0	<-40.0	<-40.0	<-40.0
1st S.L. LEVEL (dB)	MEAS.	-12.5	-14.5	--	--	-15.0
	CAL.	-13.2	-13.2	-13.2	-13.2	-13.2
2nd NULL (DEGREES)	MEAS.					
	CAL.					
2nd NULL LEVEL (dB)	MEAS.					
	CAL.					
2nd S.L. LEVEL (dB)	MEAS.					
	CAL.					

of peak RCS is normally within ± 1 dB of the theoretical value. As
the test targets become progressively larger in physical area, the
measured peak RCS is always lower than the theoretical peak RCS value.
Several factors could produce this effect on the measured data; the
most likely cause is the effect of background shadowing by the larger
targets. Since the measurements are made with a CW radar, background
nulling is inherent in the procedure. Differences in physical size of
the test and calibration targets cause differences in background level.
This shadowing effect could be reduced by the use of a standard target
of approximately the same physical cross-sectional area as the unknown
or test target.

Another effect on the measurement of peak RCS, or essentially reflec-
tivity range calibration, when a small sphere is used as the standard
target, is interaction with reflected radiation. Since the sphere re-
radiates much energy in directions other than toward the reflector,
stray radiation may add in or out of phase with the collimated radiation
normally incident on the sphere. Thus an interference pattern is pro-
duced that causes variation in the measured backscatter from the sphere
with distance to the reflector. This effect was evident on the compact
reflectivity ranges when the sphere was moved in range a distance of
several wavelengths. Maximum peak-to-peak variations of 5 dB were measured
in the backscatter from the sphere for this movement in range. The reference
value of backscatter from the sphere, which was used to calibrate the test
target measurements, was selected to be the peak RCS of the sphere as
the sphere was moved in range.

E. Alternate Measurement Procedures

The differences in the computed and measured values of peak RCS could be the result of several unrelated factors. Possible contributors to the differences are

1) changes in the value of signal leakage through the hybrid tee for the wide dynamic range of received signal,

2) the interference pattern produced by the calibration sphere as a function of the range,

3) inaccuracies in construction and surfaces of the flat plates, and

4) the difference in background shadowing by the sphere and the larger targets.

An investigation was conducted to determine if these factors could be reduced or isolated from one another. The CW breadboard radar was modified by eliminating the slide-screw tuner and inserting a variable phase-shifter and variable attenuator in the system. A simplified block diagram of this modified CW radar is shown in Figure 22. In this set-up, the background nulling signal should be unaffected by variations in the received signal level.

Measurements were made of the peak RCS of the six test targets with this modified CW radar. In these measurements a different procedure was used to establish the measured value of RCS for the calibration sphere. The backscatter signal from the calibration sphere

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TO LINE/POINT SOURCE FEEDS

UNMATCHED HYBRID TEE

LOAD

ISOLATOR

PHASE SHIFTER

3 dB COUPLER

PRECISION ATTENUATOR

PRECISION ATTENUATOR

CRYSTAL MIXER

TO RECEIVER & PATTERN RECORDER

3 dB COUPLER

ATTENUATOR

PHASE LOCKED KLYSTRON
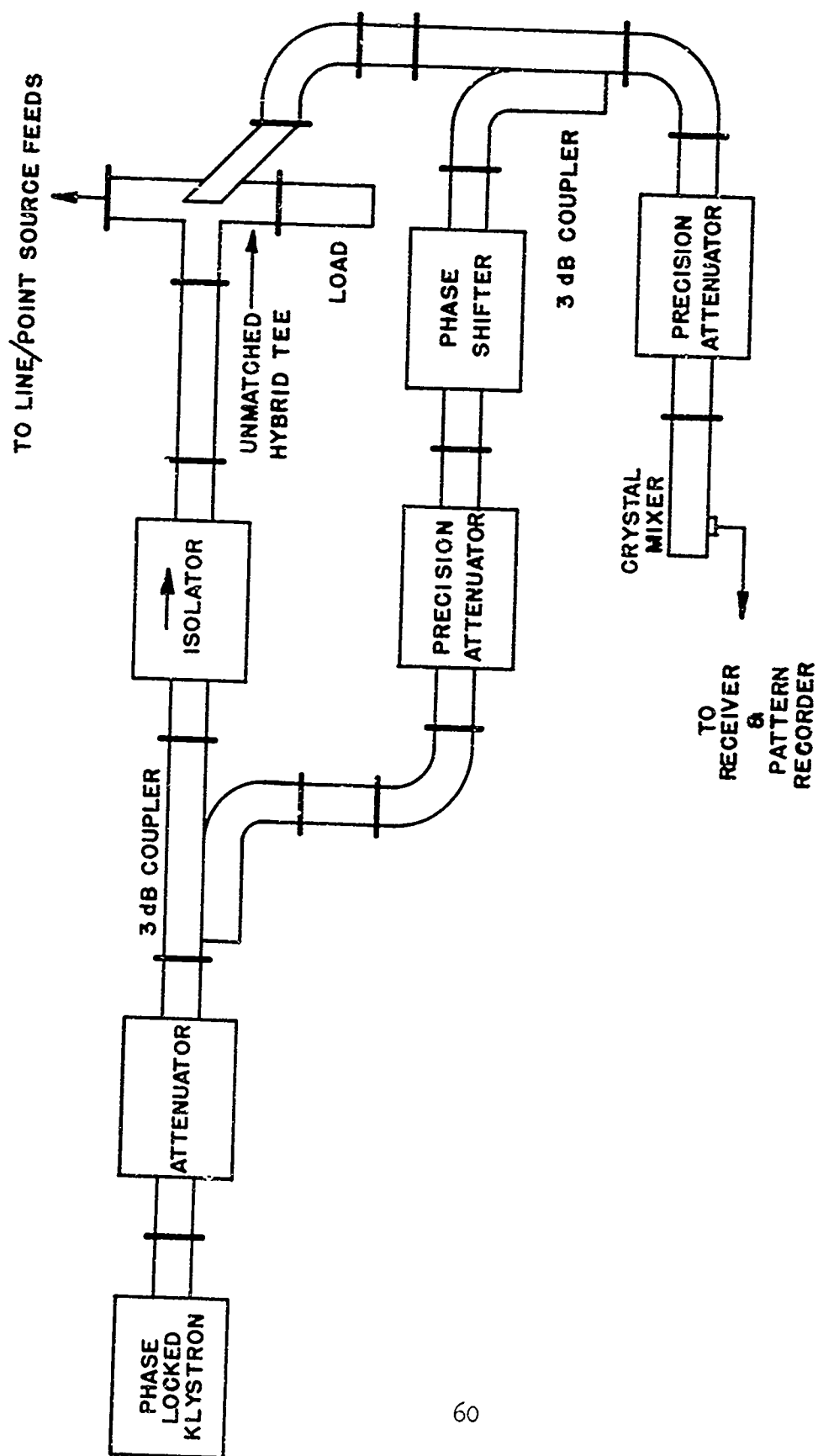
Figure 22. Block diagram of modified X-band CW radar

was recorded for movement in range of approximately two feet. The resulting interference pattern, produced by the phase addition and subtraction of the collimated radiation and stray radiation incident on the sphere, was analyzed to obtain an average value of RCS for the sphere. This average value was then used as the RCS reference value for the measurements.

Each of the six test targets was moved through the same two-foot increment of range and interference patterns were recorded. In general, the test target exhibited negligible interference effects with the largest interference patterns having less than 1 dB peak-to-peak variations. These measurements were obtained on the line-source range at each test frequency mentioned previously. The results of these measurements of peak RCS for each test target were similar to those previously obtained; the measured peak RCS values of the larger targets were approximately 2 dB below the calculated peak RCS values and the measured values for the smaller targets were very near the calculated values of RCS.

Although considerable care was exercised in fabrication of the test targets, some inaccuracies must exist in the flatness of the plate and dimensions used in the calculations of radar cross section. This type of construction error would tend to cause the measured re-sults to be lower than the calculated results, but of smaller magnitude than observed for the large test targets.

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Thus, the main factor producing the differences in measured and calculated values of peak RCS is assumed to be the difference in background shadowing between the larger targets and the small calibration sphere used as a reference. A calibration or reference target having more nearly the same physical cross-sectional area should reduce the measurement difference in RCS for the larger targets. The fact that the measured RCS values for flat plate targets of the same area but different shapes were equal within ±.5 dB substantiates this conclusion.

SECTION VI

FREQUENCY SCALING OF RADAR CROSS SECTION

In one sense, radar targets can be classified in terms of their dominant dimensions relative to the wavelength of the incident wave. Targets whose dimensions and principal radii of curvature are large in terms of wavelength can be analyzed with optical methods. Geometrical optics, physical optics, and the geometrical theory of diffraction are methods employing high frequency approximations which can be used to compute radar cross section. Such targets usually exhibit little sensitivity to the polarization of the incident wave. When radar targets have dimensions that are small in terms of the wavelength, the reflective properties are to a first approximation dependent only on the size of the target and not its shape. Significant aspect angle and polarization dependence can be observed, however, when the reflecting target is thin. Targets have been catagorized according to the principal form of scattering by Hey, et al[6] as follows:

1) wavelength large compared with dimensions - Rayleigh scattering region

2) wavelength on the same order as the dimensions - resonance region

3) wavelength small compared with dimensions - surface and edge scattering region.

These three regions are illustrated in the case of the radar cross section of a sphere. A wavelength dependence of $1/\lambda^4$, characteristic

of the Rayleigh region, is exhibited for sphere radii less than 0.1 λ. When the radius is greater than 10 λ, the variation in cross section is less than 1% of the limiting value of πr^2. The region between these two radius values displays the significant oscillations characteristic of the resonance region.

The X-band radar reflectivity measurements made on the compact ranges were in the upper frequency end of the resonance region and in the edge and surface scattering region. The radar cross section of targets in the Rayleigh region at X-band would be too small to permit detection with the CW radar used on the compact ranges. The demonstrated sensitivity of the ranges, however, would permit the measurement of the radar cross section of most targets throughout the resonance region, as well as the edge and surface scattering region.

The standard approach in frequency scaling to make radar cross-section measurements of large targets feasible is to scale in wavelengths of the incident wave by the same ratio as the target model is scaled. This scaling requires that much higher frequencies than the frequency at which the cross-section value is desired be used to permit models of practical size to be constructed. With the current compact reflectivity range configuration, targets up to approximately 3 feet in their largest dimension can be measured at frequencies up to 12.4 GHz. Thus, targets whose largest dimensions are 3 feet can be measured at X-band to simulate targets with dimensions of 9 feet, 24 feet, and 360 feet at 4.0, 1.0, and 0.1 GHz, respectively.

The construction precision of the hog-horn and parabolic cylinder in the line-source reflectivity range is greater than the minimum requirements for operation at X-band. The criterion of $\lambda/16$ for surface tolerance would allow the line-source reflectivity range to be operated as high as 70 GHz; if stray radiation proved to be too large at this frequency, a $\lambda/32$ criterion would permit operation at 35 GHz. If a K_a-band radar were constructed, targets whose maximum dimensions are 9 feet could be scaled by 1/3 and measured at 35 GHz to simulate their radar cross sections at X-band.

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions on Range Evaluation

It has been demonstrated[1,2] that far-zone antenna measurements can be obtained on the point-source and the line-source compact antenna ranges. The work described in this report shows that these same compact range techniques are applicable to measurement of radar reflectivity.

The results of this work indicate that the compact reflectivity ranges operating with the X-band CW breadboard radar are very useful tools for the measurement of radar reflectivity. The data presented demonstrate that the far-zone requirement of a uniform plane wave incident over the target aperture was achieved.

With these X-band compact CW reflectivity ranges, measurements of the backscatter characteristics as a function of aspect angle of many types of radar targets may be obtained easily. This fact is demonstrated with the included measurements of the backscatter patterns of a Claymore mine and a 50 caliber projectile.

In their present state of development the X-band CW compact reflectivity ranges can measure targets with

1) radar cross sections at X-band frequencies (8.2 GHz to 12.4 GHz) greater than -40 dBsm for the line-source range and -30 dBsm for the point-source range, and

2) largest physical dimensions of approximately 3 feet for
    uniform plane wave illumination over the target aperture.

The capabilities of the compact ranges when utilized to obtain antenna measurements have been stated previously.[1,2] The ability to measure a radar cross section as a function of aspect angle, to an accuracy equivalent to that obtained on a good outdoor reflectivity range, may now be added to these capabilities.

The operation of the compact ranges in several different enclosed laboratory areas of the Georgia Tech facilities with consistency of measurements demonstrates that their use is not confined to one particular space. The level of stray radiation measured in these various locations is comparable to that achieved on good outdoor antenna and reflectivity ranges. It may be feasible to reduce the stray radiation level further by surrounding the compact ranges with radar absorbing material, thereby improving their measurement capability for antennas and radar reflectivity. The initial cost of this enclosure would be considerably less than that required for a conventional anechoic chamber, since the $2D^2/\lambda$ criterion of range must be maintained in an anechoic chamber.

It is believed that the sensitivity level of the CW compact reflectivity ranges are vibration limited to approximately -50 dBsm and -40 dBsm for the line-source and point-source ranges, respectively. This vibration is produced by the air-conditioning compressors in the

building and other equipments common to research facilities. Location of the compact ranges on a vibration isolated pad may improve the reflectivity ranges capability considerably and allow measurements of targets having smaller radar cross section.

B. Compact Range Improvement Studies

1) Dual-polarization capability for point-source compact range.

In the present configuration both the point-source and line-source ranges are equipped to transmit vertically polarized signals. Rotation of the feed horn on the point-source compact range permits measurements to be made with any linear polarization. A redesign of the feed for the point-source compact range could add the versatility of transmitting linearly polarized signals and simultaneously receiving returns with polarizations that are parallel and orthogonal to the transmitted signal. This new feed would consist of a square waveguide horn and an X-band dual-mode waveguide coupler. The dual-mode coupler is an operational piece of hardware (designed and developed at Georgia Tech) and provides an R.F. isolation greater than 40 dB between the two orthogonal linear polarizations.

The complete description of the radiation pattern or reflectivity pattern of an antenna or radar target for one polarization does not describe completely the characteristics of that antenna or target. The radiation pattern or reflectivity pattern for waves that are orthogonally or cross polarized must be known. The ratio of the gain of an antenna for the

principally polarized signal (parallel polarization) to the gain for an orthogonally polarized signal (cross polarization) is defined to be the polarization ratio. Knowledge of the polarization ratio of an antenna is becoming of prime importance to the designers of military antenna and radar systems.

The described redesign of the feed system for the point-source compact range would provide the measurement capability necessary to determine polarization ratio. From these measured data the antenna polarization ratio as a function of azimuth angle could be obtained. With the addition of some relatively simple instrumentation, the polarization ratio pattern could be plotted directly using the antenna pattern recorder.

2) Breadboard X-band short-pulse compact reflectivity range.

A preliminary study of the design parameters required for an X-Land breadboard short-pulse compact reflectivity range is being conducted at Georgia Tech. The major advantage that a short-pulse (approximately 5 nanosecond pulse duration) system would have over the presently used CW system would be the ability to discriminate more effectively against the backscatter from the background environment.

Several problems present themselves in the actual bread-boarding of the short-pulse X-band radar. These are the generation of the 5 nanosecond pulse and the associated wide receiver bandwidth. A high pulse repetition frequency (PRF), due to the short range, can be employed to maintain sufficient power. These problems are not insurmountable, and

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the concept of a short-pulse compact reflectivity range is considered
to be feasible.

A measurement program to compare the results of reflectivity mea-
surements obtained with a pulse compact reflectivity range versus those
obtained with the CW compact reflectivity range would be worthwhile.
This measurement program could be done in conjunction with the develop-
ment of a pulse compact reflectivity range.

C. Backscatter Measurement Programs Using Compact Reflectivity Range

1) Backscatter characteristics of projectiles and other military
   targets.

The CW compact reflectivity ranges have proven to be very
good reflectivity ranges. With the existing ranges, measurements of
the backscatter return versus azimuth and elevation angles of targets
having low radar cross section (10^{-4} square meters) are possible.
Characteristics of the CW compact reflectivity range make it an ideal
"tool" for use in compiling data of radar cross section versus aspect
angle of numerous targets of military interest, such as small caliber
bullets, mortar shells, Claymore mines, etc. These data could be
plotted on a contour type format or in the form of cumulative distri-
bution curves. Data of this type would be extremely useful to the
designers and users of military radar systems.

2) Backscatter characteristics of ground and airborne antennas.

The antennas in aircraft and ground installations noticeably increase the radar cross section of the system. Since the size of most airborne antennas is compatible with the size limitation of the existing compact ranges (approximately 30 inches), the compact reflectivity ranges would be very useful in a program to investigate methods of reducing the backscatter from airborne radar antennas. The results obtained from an investigation for the reduction of backscatter from airborne antennas also would be applicable to many ground-based antennas.

3) Backscatter from clutter.

One of the limiting parameters of many radar systems is the backscatter from ground clutter. It is known that seasonal conditions, tree type, surrounding vegetation, polarization, wind speed, and moisture content cause variations in the reflectivity of a given area of clutter. Very little is known about the individual elements such as the backscatter from leaves, branches, pine cones, etc. that, grouped together, compose this clutter. The capability of the compact reflectivity ranges to measure targets having low radar cross sections but relatively large physical apertures, plus the advantage of a stable indoor environment, make them desirable tools for investigating the individual elements composing clutter. Environmental control of the individual clutter targets, such as wind speed, moisture content, temperature, etc., could

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be readily achieved. A measurements program designed to investigate the various constituents of clutter would provide the radar designer with valuable information for radars to detect targets in clutter.

4) Statistical reflectivity characteristics of radar targets and clutter.

Facilities exist at Georgia Tech to generate statistical data on the radiation characteristics of antennas as a function of azimuth angle. These data may be plotted in the form of cumulative gain distribution curves. Data in this form are very useful design information when mutual interference between two or more antennas must be considered. This statistical method of data presentation is applicable to radar reflectivity measurements also since the target will be viewed from a wide range of aspect angles. Statistical analysis could be applied to the radar reflectivity measurement programs outlined above.

D. Summary

The ability to measure the gain and radiation pattern of a microwave antenna on the compact antenna range has been demonstrated previously. Work performed in this report demonstrated that these same compact range techniques are applicable to compact radar reflectivity ranges. The advantages of the compact ranges over conventional antenna and reflectivity range are reduced range requirements, lower initial expense,

lower R.F. transmitter power, small physical space required, freedom
from adverse weather conditions, and convenience of operation. The
recommended program in this report would improve and expand the capa-
bilities of compact antenna and reflectivity ranges.

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13 ABSTRACT

The purpose of the work described in this report was to investigate the possibility of applying the concepts employed in the compact antenna ranges to the operation of compact reflectivity ranges. This work was conducted at X-band frequencies (8.2 to 12.0 GHz). A continuous wave(CW) breadboard radar was fabricated using common laboratory components and equipment. This CW breadboard radar comprises the transmitter and receiver equipments used with the compact range reflectors.

Selected test targets, whose theoretical backscatter patterns were calculable, were used in the investigation. The backscatter patterns of these test targets as a function of azimuth angle were measured using the point-source and line-source CW reflectivity ranges. Comparisons were made of the measured backscatter patterns and the calculated theoretical backscatter patterns. The test targets varied in physical area from a 4 square-inch flat plate to a 100 square-inch flat plate. A 2.5 inch diameter conducting sphere was used as the calibration target.

A study of target support structures for use on reflectivity ranges led to the fabrication of a cellular plastic (Styrofoam FR[1]) right conical column with a serrated surface. The serrated surface was designed to produce diffuse rather than specular scattering from the support structure.

(Continued)

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[1] A registered trade name of the Dow Chemical Company

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Ranges (Establishments) Test Facilities (Antenna Test Range Techs) Radar Cross-Section Measurements Reflectivity Ranges						

Abstract (continued)

The sensitivity level of the developed compact CW reflectivity ranges is limited by vibration to -50 dBsm for the line-source range and -40 dBsm for the point-source range. This sensitivity or null level limits the measurement of radar cross section to values greater than -40 dBsm and -30 dBsm, on the compact line-source and the compact point-source reflectivity ranges, respectively. The collimated beam illumination characteristics of the compact ranges limit the measurement of radar cross section to targets approximately 36 inches in diameter or smaller. Measured backscatter patterns obtained on both compact reflectivity ranges compare very favorably to those calculated.